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THE IRON WORK FOR THE DOME OF THE PROPOSED GOVERNMENT BUILDING, WORLD'S COLUMBIAN EXPOSITION, CHICAGO, ILL.*

By JAMES C. McGUIRE, Jun. Am. Soc. C. E.

It is the purpose of the author of this paper to outline as briefly as possible some of the characteristic features of the work, which may be of interest to engineers because of its size and method of construction. It is among the tallest domes in the world, which are built of any of the malleable metals. That at Vienna, Austria, exceeds it, being 279 feet high, but is entirely different in construction, being built like the frustrum of a pyramid instead of circular. This dome has been designed as only a temporary structure, and probably will not remain in position longer than one year.

The Foundations.—The soil in the part of Jackson Park, where the dome is to be built, has, by borings, been ascertained to consist for a depth of about 3 feet on top, of black soil; then for 11½ feet of quicksand; under this, 14½ feet of soft clay; then hard pan was penetrated for a distance of 13 feet. The dome rests on sixteen columns, and under each column

* Designed by the author, in the office of the Supervising Architect, Treasury Department, Washington, D. C.

there are fifteen piles. The specifications require that, before getting out the piles for the work, the contractor must drive test piles in order to determine the actual length of pile required; each pile to be driven until a hammer weighing 2 500 pounds, falling 25 feet, will not sink the pile more than 1 inch, or equivalent thereto, and the head of the pile to remain whole, sound, and without split or flaw. As there is a load of about 418 000 pounds on each column, if this be equally distributed each pile will be required to carry 27 860 pounds; and, as nearly 90 per cent. of this is wind load, there will be no difficulty in securing a good foundation. These piles have been driven, and are from 20 to 30 feet in length. On top of the piles are three courses of cribbing for securely fastening together the heads of the different piles, and rendering the whole rigid and firm; this cribbing is securely bolted to the piles, and on it rests the shoe of the column, which is built of eye-beams and plates for the purpose of distributing the pressure over a larger area than is occupied by the base of the column.

The Dome.—The dome stands in the center of a rectangular building, 420 x 350 feet (see Plates I and II); but it is built entirely independent of the main building. At the floor level the dome proper (not including the outside sheathing) has an external long diameter of 118 feet, and it rises vertically 115 feet above the floor level of the rotunda, to the spring line. The ironwork finish is sixteen sided, but is architecturally treated, as seen from the interior of the main building, as an octagon (that is, the outside of the dome below the roof of the main building). After the dome emerges above the roof, the finish is sixteen sided until the cornice below the windows which extend around the dome is reached, and from thence it is cylindrical to the springing line (see Plate I). From the springing line the exterior is the surface of a sphere, very much on the order of the dome of the United States Capitol at Washington, D. C. The finish of the inside is sixteen sided throughout the entire height.

The columns supporting the dome have a depth of 6 feet from back to back of angles, and are composed of four angles 4 x 6½ inches, extending to the springing line, with two 14 x ½ inch cover plates which extend about 56 feet above the floor; the angles of the columns are latticed with double latticing at about 45 degrees inclination, the latticing being composed of a 3 x 5 inch angle. These columns are braced horizontally by struts in pairs, which form continuous

PLATE I.
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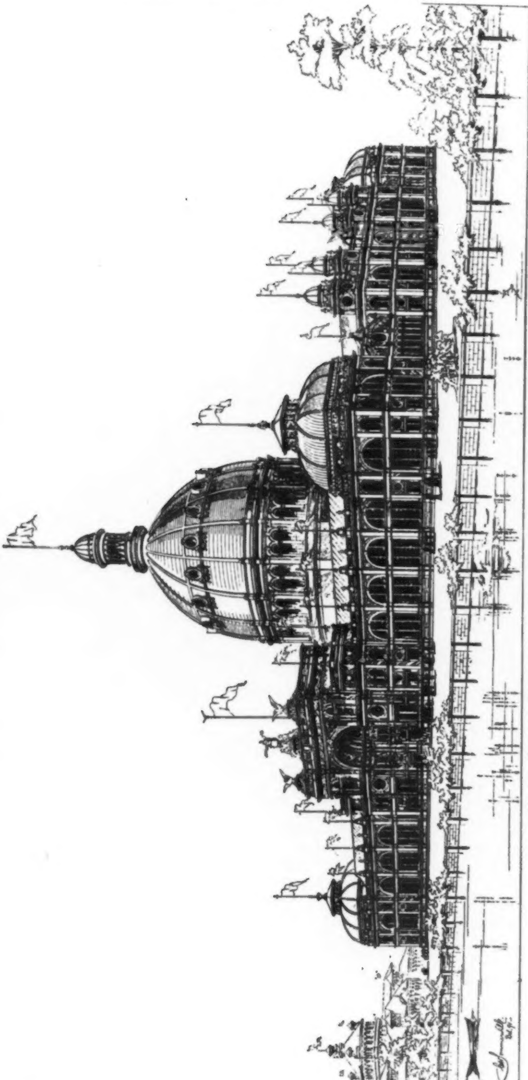

= UNITED STATES GOVERNMENT BUILDING = WORLD'S COLUMBIAN EXPOSITION =

PLATE II.
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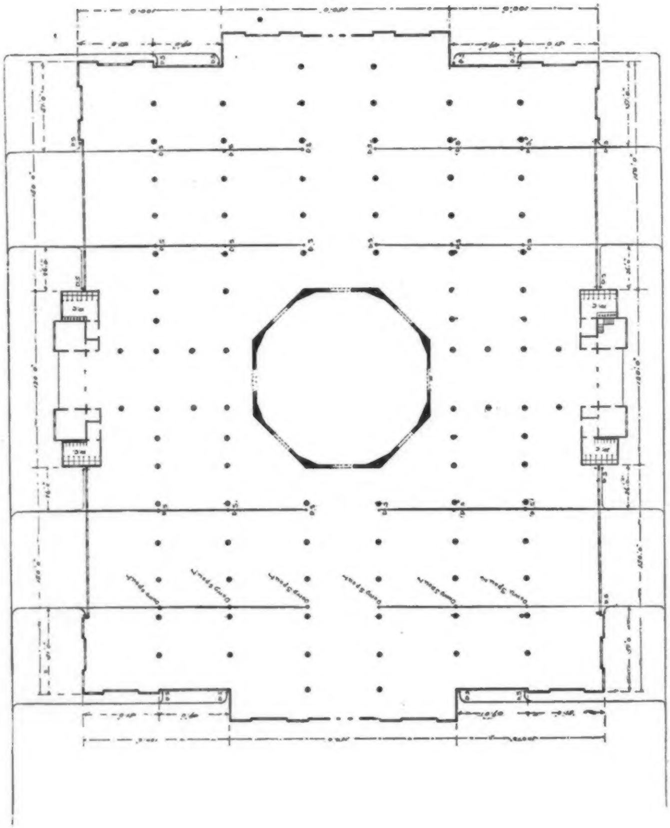
FIRST FLOOR PLAN.



rings around the dome, each pair being from 20 to 26 feet apart; there is one pair of struts just below the springing line, and another under the floor, with four intermediate pairs. The outside one of these struts is as near the outside flange of the column as was possible to place it; while the inside strut is moved outwards a distance of 1 foot $10\frac{3}{8}$ inches, because the rods which are attached to the struts and are in every other panel, would (if the struts were set against the inside flange of the columns) show after the interior finish is in place, as there is a recess between the columns.

These struts are composed of four 3 x 4 inch angles, double latticed, with 2 x $\frac{5}{16}$ inch lattice bars, and are 18 inches deep; except the first strut above the floor, which is 24 inches deep, and is latticed with double latticing of $2\frac{1}{2}$ x 3 inch angles. These latter struts carry a basket balcony, the floor of which is 28 feet 6 inches above the first floor level; there being one of these balconies in every other panel over the eight entrances to the rotunda of the dome (see Plate III). The entrances, also, are in every other panel, as the bracing between the struts occupies the alternate ones. Two of the balconies are not accessible, the others are entered by a stair which leads up between the columns of the dome and between the struts. There are four stairways leading from the first floor to four of the balconies, and two of the balconies are entered by going from these to a gallery in the main building outside of the dome, and from this gallery into the balconies in question.

The balconies extend back between the columns, and four of them, as previously stated, have a stairway entering on one side, which comes up through the columns. Directly opposite the landing of the stairs, and on the opposite side of the balconies, there are four stairways starting, which extend up to the gallery, the floor of which is 75 feet above the floor of the rotunda. This gallery extends entirely around on the inside of the dome, and is supported on brackets fastened to the inside of the columns; eyebeams extend from one bracket to the other, upon which the floor joists are fastened, which support the floor.

It is not the intention to admit the general public above this level, but there is provided a single stairway which leads from the gallery to the lantern; which continues on through the ribs of the dome and between the struts, until it is above the springing line of the dome, when it turns and goes up parallel to one of the ribs, it being suspended from

this rib by 1-inch round rods. The stairs are braced at each suspension point by five-eighth-inch guy rods, which extend out on either side and are fastened to the struts of the dome. The stairs are composed of two 6-inch channels, which form the stringers, with pine treads bolted to angle brackets, which are fastened to the stringers after the usual manner; and a 1½-inch gas pipe railing on either side of the stairway, with the balusters of the same screwed in cast iron lugs which are bolted to the stringers.

At the gallery level there are windows in every panel, extending around the dome, which made it necessary to do away with the rod bracing entirely at this level. In order to strengthen the columns at these points, large ⅜-inch thick plates, as knee-braces, were used, both at the outside and inside strut; these plates being stiffened by 3 x 3 inch angles. These plates were made as large as possible without interfering with the window openings, the plates being on the struts, both above and below the windows (see Plate VII).

From the springing line the ribs converge towards the center of the dome. The depth of the ribs is 6 feet at the springing line from back to back of angles, and at the top of the crown of the dome, it is 3 feet from back to back of the angles, with a circular opening at this point of 17 feet diameter, over which the lantern is placed. The ribs above the springing line consist of two 6 x 6 inch angles for each flange; the ribs are divided into fifteen panels, by two 3 x 5 inch angles, which are normal to the exterior flange of the rib, making each panel a little less than 6 feet long; and in each panel there is double latticing composed of 5 x 3 inch angles. Strut No. 5, at the springing line, takes the outward thrust of the ribs of the dome; and the ring at the top of the dome, which is 3 feet deep and has a web ⅜-inch thick, with chord angles 3 x 5 inches, takes up the corresponding inward thrust. On top of this ring, and at a point 180 feet 10 inches above the floor of the rotunda, the lantern starts, and there is a rib of the lantern for each rib of the dome, to which latter the ribs of the lantern are connected. At every third panel point of the ribs above the springing line there is a strut, which is the full depth of the rib, composed of four 3 x 3½ inch angles, double latticed, with 3 x 3 inch angles; there being four rings of such struts, with rod bracing between them, the rods continuing up in every other panel between the ribs; there being only one set of these rods above the springing line and fastened to the inside flange of the struts.

At panel points where there are no struts the entire depth of the rib, there are struts 18 inches deep, which form continuous rings around the dome, and act as purlins. These purlins are composed of four chord angles, 2½ x 3½ inch, with double latticing of 2 x $\frac{5}{16}$ inch bars. To these struts and the deep struts, at intervals of 2 feet, are bolted 2 x 4 inch timbers which run vertically, and to which the 1-inch sheathing is nailed, the sheathing being nailed diagonally.

The ribs of the lantern are composed of four 3 x 3 inch angles, latticed with 2 x $\frac{5}{16}$ inch lattice bars; the ribs are braced by horizontal rings, which extend around the lantern, and are composed of a $\frac{5}{16}$-inch plate, with a 3 x 3 inch angle, riveted to the top and bottom of this plate; these plates being used in pairs, one on the outside and one on the inside flange of the ribs of the lantern. Great difficulty was found in getting suitable bracing between these rings, as the columns of the lantern are so close together that if there are rods between all columns, the angle of inclination becomes very acute; so the method was adopted as shown on the drawing of the lantern. This lantern is 47 feet 1½ inches high, making the total height from the floor of the rotunda, to the top of iron-work, 227 feet 11½ inches. As there is a lot of ornamental work on the outside of this, the height to the top of the lantern may be said to be 235 feet 5½ inches, and to the top of flag pole is about 275 feet.

At about the springing line on the interior of the dome, the diaphragm starts, with a radius of 53 feet 4 inches. It is composed of vertical ribs of two 2½ x 3 inch angles, suspended by ⅝ inch rods from the main ribs of the dome. Upon these ribs, at intervals of 2 feet 4½ inches, are the purlins, composed of 3 x 3 inch angles, to which the galvanized covering of the diaphragm is fastened. There is a circular opening in the top of the diaphragm 16 feet diameter, and over this a canopy, which is a portion of the surface of a sphere with a radius of 11 feet 8½ inches.

Calculations.—It is not the intention of the author to go fully into the calculations embraced in the design of the proposed structure, as it would be both tedious and long, and therefore only the general method which was adopted will be given.

First, the stresses in the dome proper were found and then in the columns. The assumption to start with was that the dome is a braced arch hinged at the crown and ends, the ends being at the springing line; as a matter of fact it is all riveted up tight. The vertical loads were determined on the assumption that, including wind, snow, and

the dead weight of the material, the vertical load would be 50 pounds to the square foot on the horizontal projection of the surface of the dome.

The braced arch was first considered, of course, as of single intersection for the calculations, and then as of double intersection, considering one-half of the stress to be carried by one member of a panel in tension, and by the other member of the same panel in compression.

The diagram for these stresses is the one marked "Vertical Loads" (see Plate XI). One member of this diagram had to be computed, the simplest of which was the outward thrust. This was found by taking the panel loads on the horizontal projection of the surface of the dome and considering them as acting at the panel points, and taking the sum of all the moments of the forces around the crown. Since the structure is in equilibrium, this is equal to the moment of the outward thrust by the depth; hence dividing the sum of the moments of these forces as previously found, by the depth, we have the outward thrust; then by the diagram of forces it is seen that a normal force of unity, puts a stress of tension in the struts at the springing line of 2.55; and hence we get the tension in these struts by multiplying this normal thrust by 2.55.

The sum of the panel loads between the crown and springing line is equal to the reaction, and having this and the horizontal thrust, which we will call "T," the diagram was constructed from which the stresses in all the members of the dome were easily found. The vertical loads are given in the table and are marked "V." It is to be noted at panel one, that we have the dead and live load of the lantern acting at this point. The balcony around the lantern has been considered filled with people, the load being at 80 pounds per square foot.

The next forces to be considered are the horizontal wind forces acting on the lantern. As there are the same number of ribs in the lantern as in the dome, the author has taken the vertical projection of one panel of the lantern, assuming the wind to blow perpendicularly to this panel with a force of 50 pounds per square foot (this is a very high value, but considering the exposed position which the lantern occupies, it is not far on the safe side), this force on the lantern gives us the shear at the base; and to find the moment which this force exerts at the foot of the lantern, we have the shear multiplied by the distance to the center of pressure, which is at one-half the height of the lantern.

Stresses in Members of Truss.—(See Plate XI and Fig. 1.)

Top Chord.

No.	2	4	10	12	18	19	26	28	34	35	41	42	49	50	57	60
V	—11 100	—9 100	+1 100	+2 650	+4 600	+7 000	+3 750	+6 250	+200	+2 400	—3 750	—2 200	—6 100	—5 250	—6 350	—5 350
L	....	—31 500	+32 200	—32 200	—33 700	—33 700	—36 500	—36 500	—40 700	—40 700	—46 500	—46 500	—56 000	—56 000	—63 800	....
H	....	—28 000	—66 200	—67 700	—86 500	—88 700	—90 700	—93 200	—82 500	—84 600	—64 000	—65 500	—37 700	—38 000	—11 500	....

Bottom Chord.

No.	1	6-8	14-15	22-23	30-31	37-38	45-46	53-54	59
V	—30 500	—32 700	—36 800	—33 200	—25 200	—16 000	—8 900	—5 400	—5 000
L	....	+29 200	+30 100	+32 000	+34 800	+38 700	+44 500	+54 300	....
H	....	+51 300	+79 300	+86 200	+77 500	+57 600	+30 000	+1 000	—14 600

Diagonals.

No.	C	5	9	13	17	21	25	29	33	36a	40	44	48	52	56	
V	....	+7 000	—5 800	—600	—800	—5 350	+2 800	—7 350	+4 400	—6 850	+3 750	—4 500	+2 000	—2 000	+100	....
L	+2 600	+3 000	+4 300	+2 800	+5 100	+2 500	+6 200	+2 300	+7 800	+2 500	+9 500	+2 300	+13 600	+2 000	+1 100	....
H	....	—29 500	+26 700	—12 000	+13 400	+3 000	+2 500	+12 500	—6 000	+18 000	—11 500	+19 700	+16 006	+17 500	—15 600	....

Radials.

No.	3		11		20		27		36		43		51		58	
V	+5 800	....	—600	....	—1 600	....	—2 200	....	—2 450	....	—2 000	....	—1 400	....	—1 350	....
H	—4 500	....	+200	....	+2 500	....	—4 000	....	+5 000	....	+4 200	....	+3 000	....	+6 000	....

The stresses in the various members from this force are marked "L" and are found by the diagram of forces (Fig. 1); having calculated first the stress in one member, No. 57, which is equal to the moment previously found divided by the perpendicular depth of the rib at this point, from this the diagram was easily constructed; we could have found the stress in any other member by simply considering the truss at any point as having to resist this moment. It will be noticed from the table that on approaching the spring line where the depth of truss becomes greater, the chord stress decreases. The chord stresses may be found at any

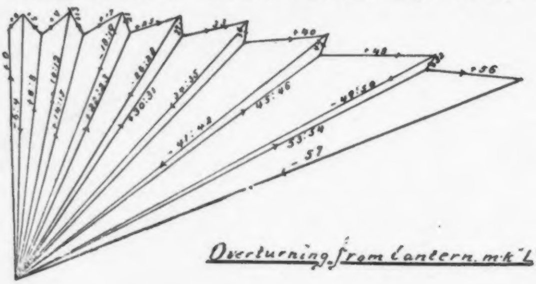


FIG. 1.

point by simply dividing the moment previously found by the perpendicular depth of the rib at the desired point.

Next to be considered is the effect of the horizontal wind force on the dome itself. This has been done in the same way, practically, that the stresses from the vertical loads were found. The wind has been taken at 50 pounds per square foot and considered as acting on the vertical projection of one panel, and the panel loads have been taken as acting at the panel points; from this the reaction was found by the method of moments both at the top and bottom of the rib. The stresses thus found are marked "H" (Fig. 2) and were taken for the right hand portion of the rib, because of convenience, and only the left half of the arch has been shown in the plates.

Stresses in Rod Bracing.—Rod bracing has been used in every other panel, extending from the ground to the lantern. Since we wish all the rods around the dome to bear equal stresses when the wind is blowing, the component borne by each will be in proportion to the projection of their lengths on a plane parallel to the direction of the wind. By inspection it was first found in what direction in reference to a braced

panel the wind would have to blow, in order that this projection might be a minimum. The wind can blow perpendicularly to a braced panel, and perpendicularly to an unbraced panel, and only at points in between. Now the projection of the rods in the direction of the wind when the

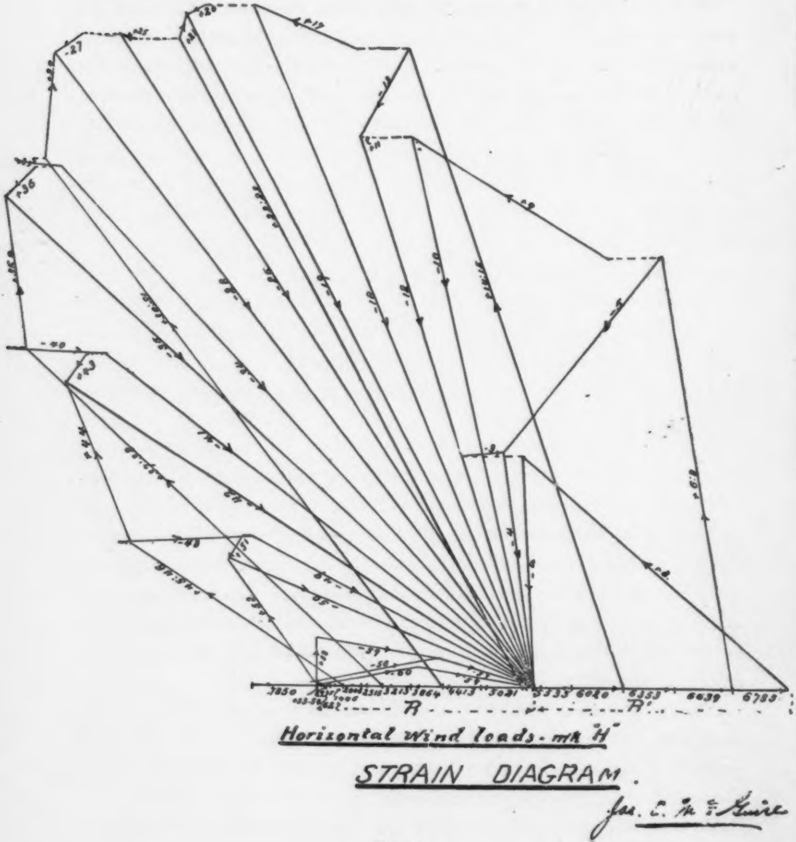


FIG. 2.

wind is blowing perpendicularly to a braced panel (the panel length being 23 feet) is $111\frac{2}{10}$ feet; and when the wind is blowing perpendicularly to an unbraced panel it is 120 feet; therefore, when the wind is blowing perpendicularly to a braced panel it is more severe on the rods than in

any other direction from which it can blow. Consequently, each panel of rods carries twenty-three divided by one hundred and eleven and two-tenths, which is equal to two hundred and six thousandths of the entire thrust on the structure.

Now when taking the pressure on a circular structure considered as a whole, the value of that pressure is proportinal to six-tenths of the total pressure on its vertical projection. The rods in the dome are only between the deep struts which are in every third panel, three panels of the rib being equal to one panel of rods. Now for the first set of rods in the dome we have acting at the top the shear from the lantern, which is equal to its vertical projection multiplied by the wind pressure per square foot (or, the same thing, its diameter multiplied by its height by the pressure per square foot). To this we have to add half of the first panel load on the rods, which we consider acting at the top, found by taking the diameter of the dome at this point multiplied by the pressure per square foot, adding this to the shear from the lantern, and taking six-tenths of the total, gives us the total stress which has to be taken up by the rods at this elevation, and, as previously stated, all the rods around the dome carry the same, each rod has to be designed to carry two hundred and six thousandths of this total pressure. Multiplying this result by the secant of the inclination of the rods to the struts, measured in the plane of the rods, we have the stress in the rods; and so on for each deep strut. Considering one-half the panel load above and one-half the panel load below to act at the point in question, and adding, of course, what the rod above brings down; and so on down to the springing line. When this point is reached we have two sets of rods, and two sets of struts, one on the outer flange of the column, and one near the inner flange of the column.

The rods in the first two panels above the rotunda floor are of the same size as they are in the third panel above, as the dome is protected to about the level of the second strut above the floor by the main portion of the building, which is built entirely independent of the dome.

Stresses in Columns of Dome.—Starting at the springing line the stresses are induced by three different causes:

First.—The vertical, live and dead loads.

Second.—Overturning force of the wind on that portion of the dome above the springing line.

Third.—Direct wind, transmitted to the columns through the rods.

Taking the first of these causes, we have acting at the top of the columns or the springing line a certain load caused by the vertical pressure on the dome, which we have already found; and the author has assumed that for every lineal foot on each column below the springing line there is a dead load of 200 pounds.

2d. The overturning effect of the wind on that portion above the springing line. This was found by taking the same panel loads as were used in determining the stress in the rods; first taking the pressure on the lantern, then taking six-tenths of it, as we did before, multiplying this pressure by the distance from the springing line to the center of pressure, we get the moment of this force around the springing line, and treating each of the panel loads the same, that is, multiplying them by the vertical distance from the springing line, and then taking the sum of these moments, we get the moment of the wind about the spring line; this has to be resisted by the columns, and assuming each column to carry an amount proportionate to the different diameters of the dome, measured from the head of one column, to the head of the column directly opposite, and taking the sum of these distances, we have the leverage:

2 x 116	feet	= 232	feet.
2 x 98	"	= 196	"
2 x 66	"	= 132	"
2 x 23	"	= 46	"
		606	"

we have the total leverage by which this amount is resisted as 606 feet, and dividing the total moment from the wind as found above, by this, we have the down push on all the columns.

3d. Direct wind stresses: These stresses were found by using the same panel loads as were used in determining the stresses in the rods; only we multiply by the tangent of the inclination to the vertical, adding, of course, at each strut what has previously been brought down to that point (Fig. 3).

Stair Openings.—Where the stairway passes through the columns, of course, the latticing of the columns has to be omitted, and the maximum openings that could be allowed were determined as follows: Let X equal the maximum opening; then we have the moment of inertia of the section of one flange of the column, around an axis parallel to the long side of the angles and through the center of gravity of this section (as it is

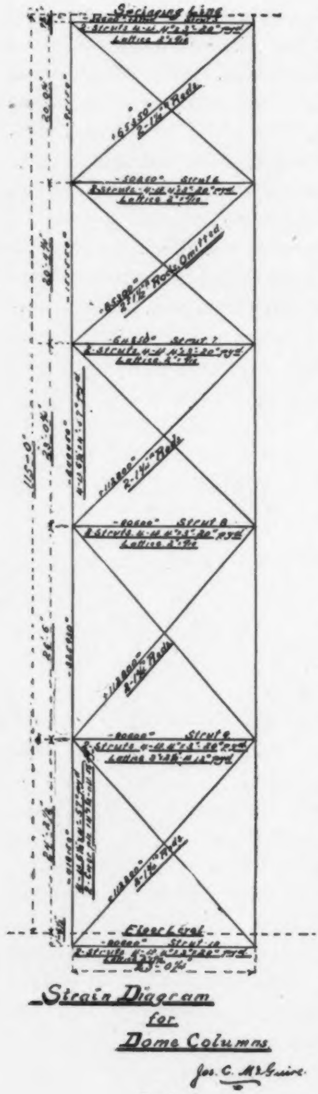


FIG. 3.

about this axis that the column will fail if the opening is made too great) is to X, as the moment of inertia of this same section, around an axis parallel to the short legs of the angles, and through the center of gravity of the section, is to the distance between struts ; having solved this equation for X, this opening was found.

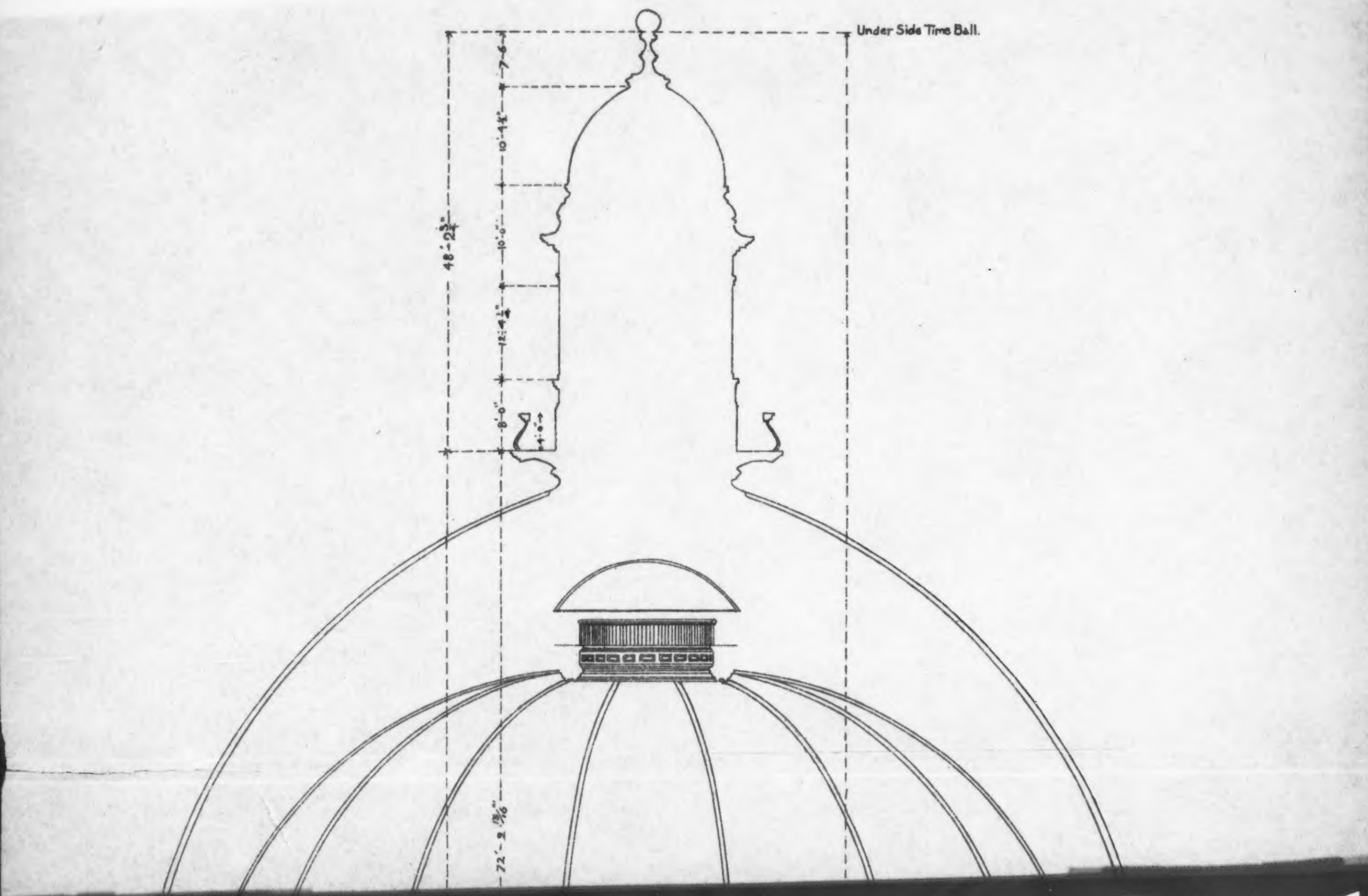
The uplift at the foot of each column was found by simply taking the moment of all the horizontal forces around the base of the columns, and as this moment has to be resisted by the uplift on the anchor bolts (plus the dead weight of the dome), multiplied by the effective diameter of the dome; we have this moment of all the horizontal forces, divided by 606 (which we previously found to be the effective diameter of the dome). From this resultant the dead weight was subtracted, leaving the actual uplift on the anchor bolts.

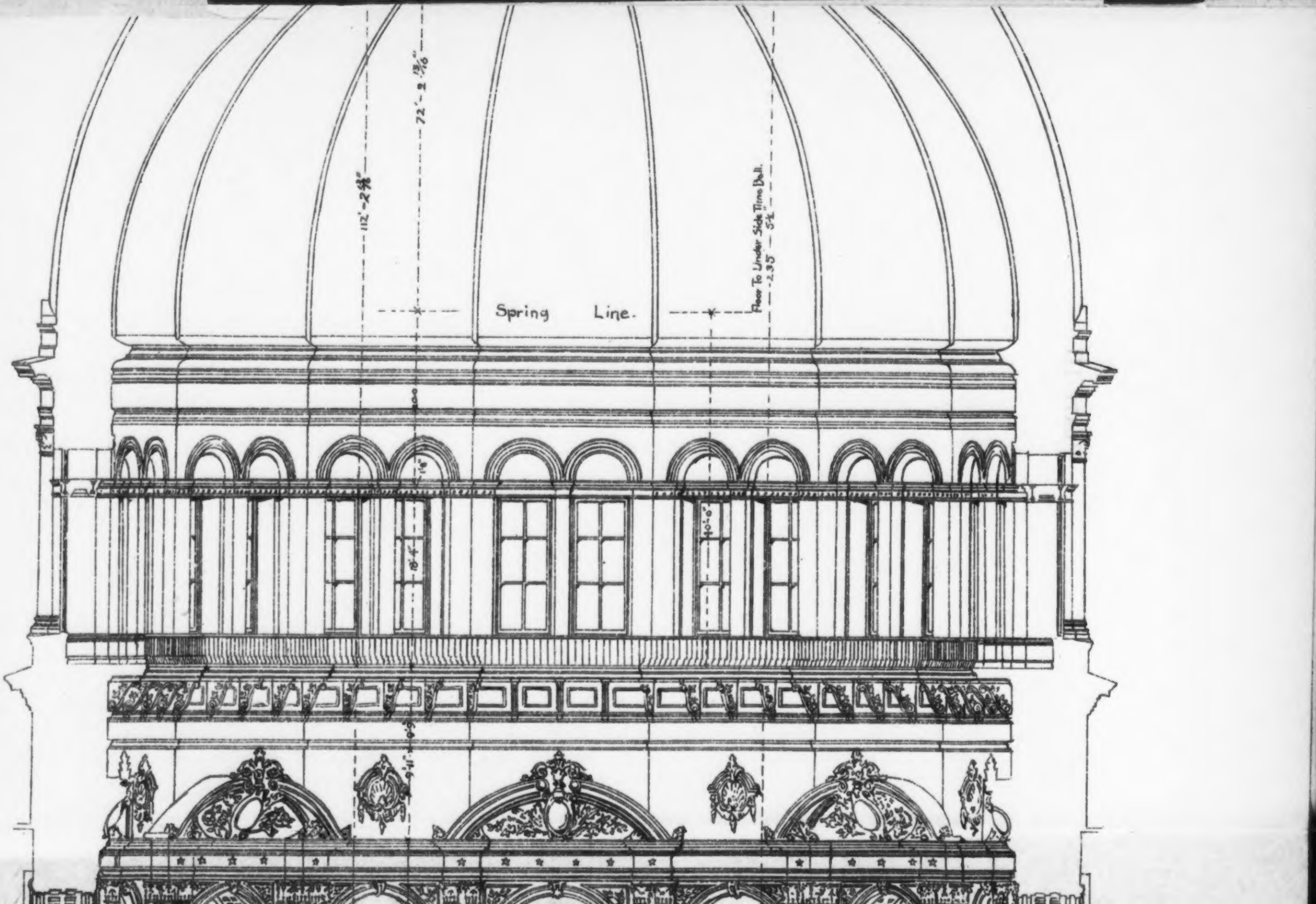
Specification.—The material specified for the dome is mild steel, with an ultimate tensile strength from sixty to sixty-eight thousand pounds per square inch, with a percentage of elongation of not less than one million two hundred thousand divided by the ultimate tensile strength in pounds per square inch ; and with a percentage of reduction of area of not less than two million four hundred thousand divided by the ultimate tensile strength in pounds per square inch.

The estimated weight of the iron and steel included in the lantern and dome is about 1 265 000 pounds, the contract for furnishing which is held by Hugh, Ketcham & Co., of Indianapolis, Ind. All of this material at the date of writing has been rolled, and the contract requires that the ironwork shall be finished and in place by the fifth day of June, 1892, under a penalty of $100 for every day's delay beyond that date.

All material of the dome is steel, except the rods, which are iron, and also some lattice bars for the struts.

The author desires to express his thanks to Mr. H. W. Hodge, Chief Engineer of the Union Iron Works of New York City, for valuable assistance as to the method of calculations received from him, while designing this work.


Under Side Time Ball.
48'-2¼"
7'-6"
10'-4½"
10'-0"
12'-4¼"
8'-0"
4'-0"
72'-2 13/16"



Spring Line.
112'-2⅜"
72'-2 13/16"
Floor To Under Side Time Ball.
235' - 5½"
40'-0"
18'-4"

PLATE III.
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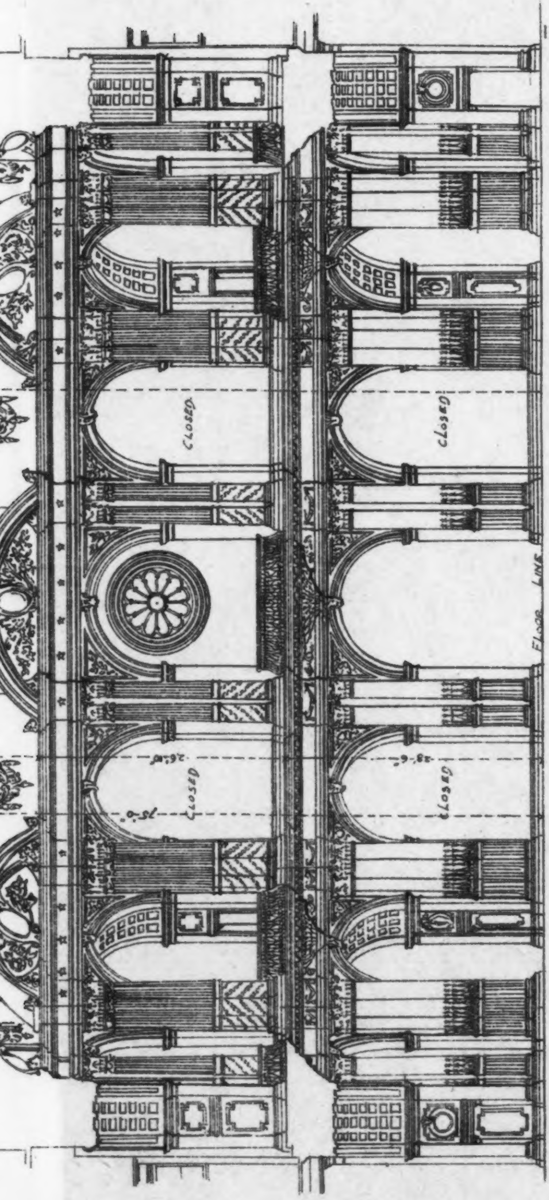
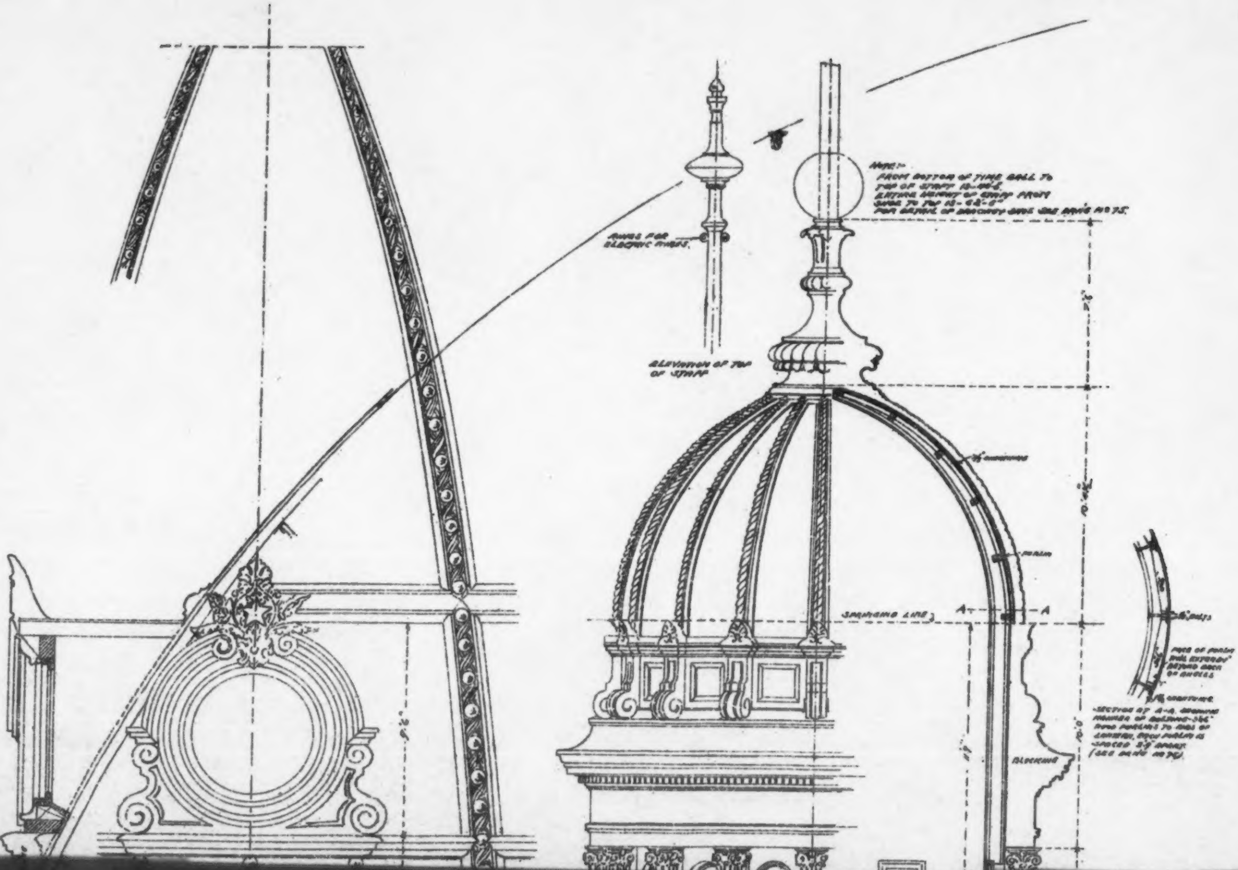
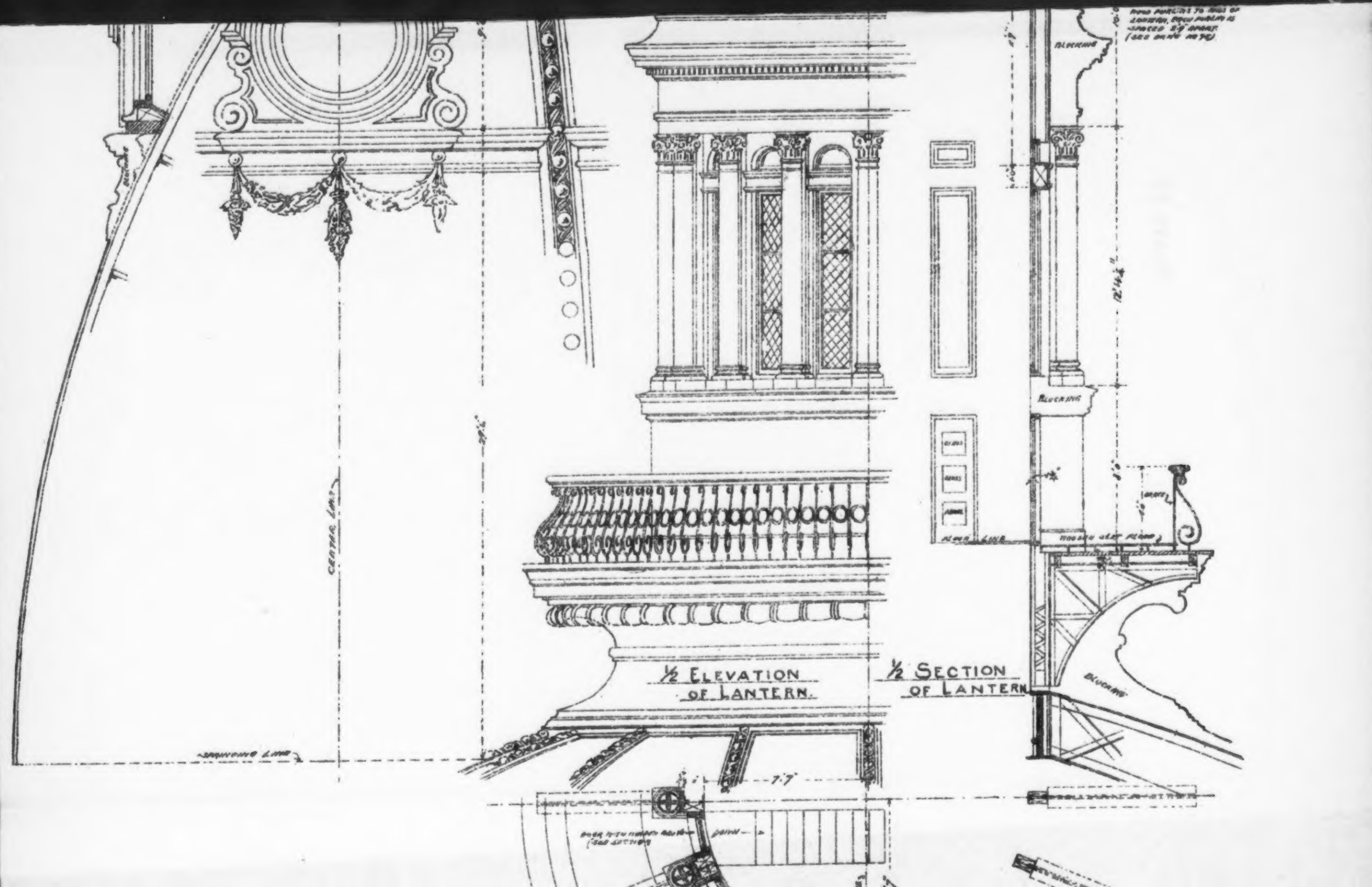


SECTION THROUGH DOME
EAST AND WEST.



ELEVATION OF TOP OF STAFF
SPRINGING LINE
BLOCKING



½ ELEVATION OF LANTERN.
½ SECTION OF LANTERN
CENTER LINE
SPRINGING LINE
BLOCKING
BLOCKING
BLOCKING
BLOCKING
12'-4½"
7'-7"

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
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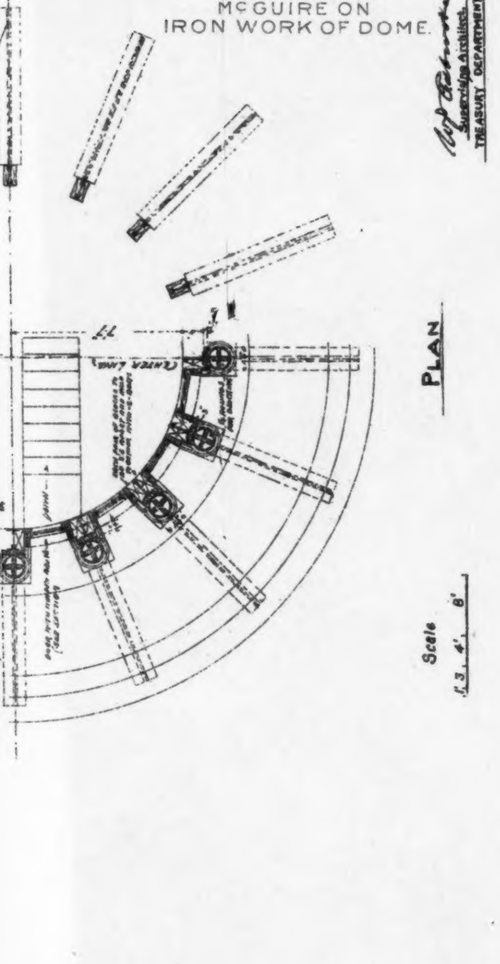
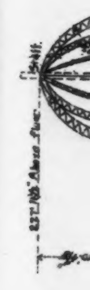
McGUIRE ON
IRON WORK OF DOME.





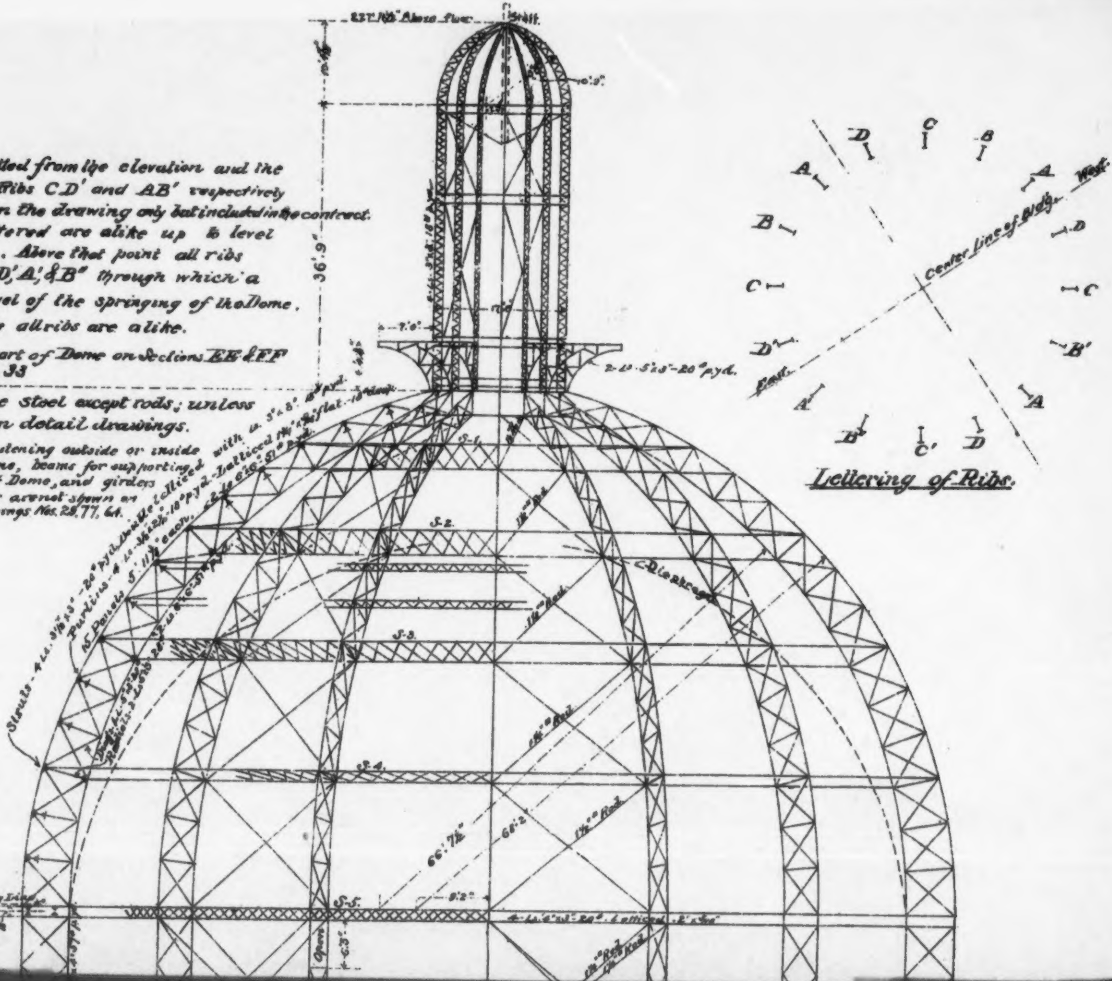
Notes.

Ribs D' & B' are omitted from the elevation and the bracing between Ribs C D' and AB' respectively is also omitted from the drawing only but included in the contract. Ribs similarly lettered are alike up to level of second Balcony. Above that point all ribs are alike except D', A', & B" through which a stairway passes to the level of the springing of the Dome. Above the springing line all ribs are alike.

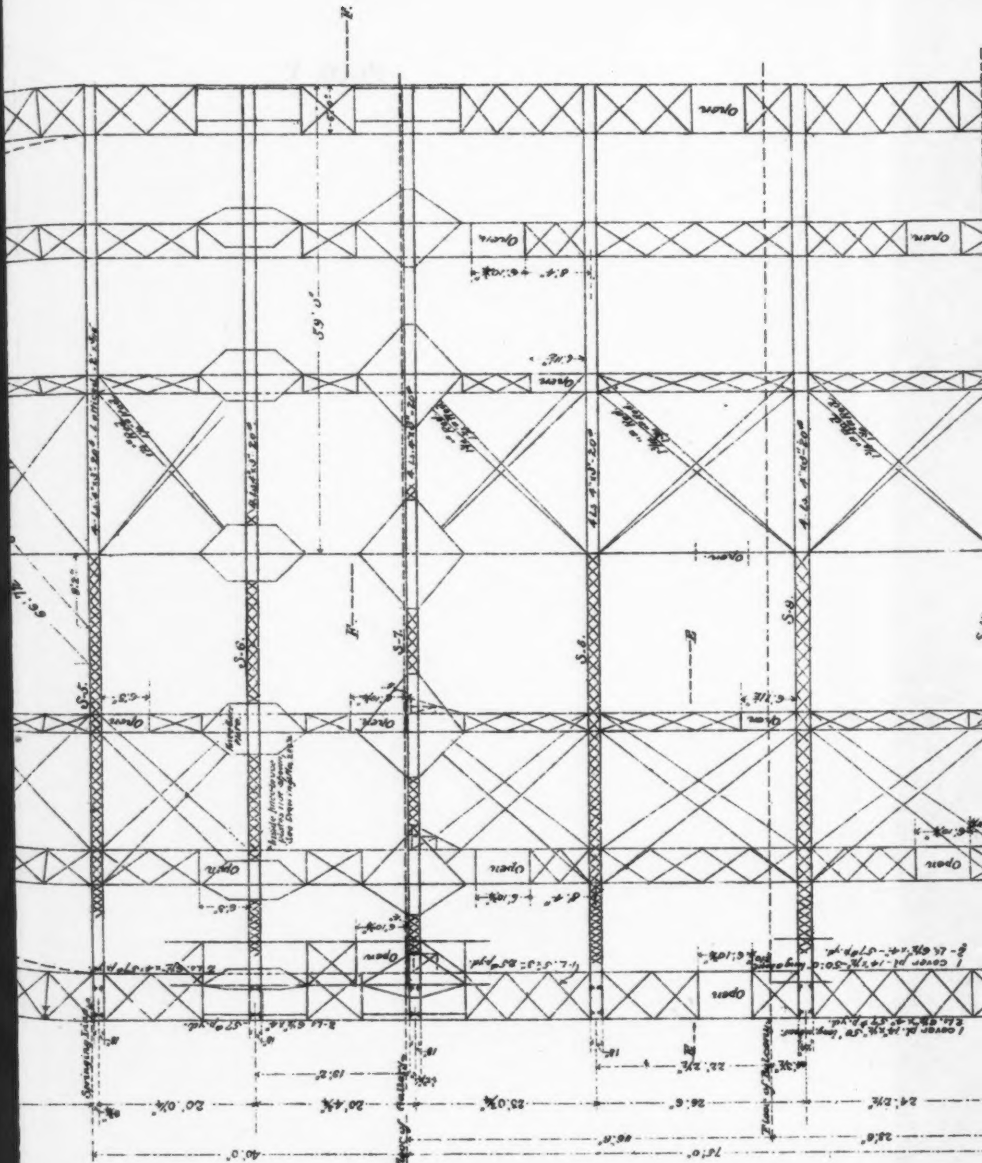
For plan of remaining part of Dome on Sections EE & FF see Drawing No. 33

All material of Dome steel except rods; unless otherwise noted on detail drawings.

Beams or Ls used for fastening outside or inside sheathing to ribs of dome, beams for supporting roofs attached to ribs of Dome, and girders carrying gallery floor are not shown on this Drawing. See Drawings Nos. 28, 77, 64.

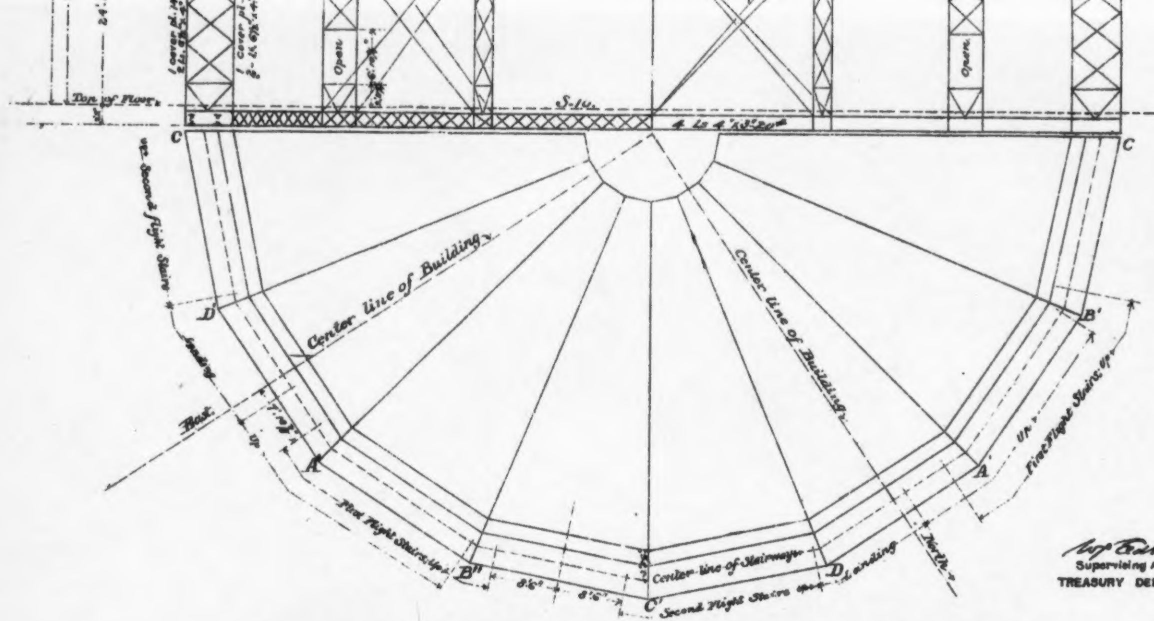


Lettering of Ribs.



Open
S-5
S-6
S-7
S-8
S-9
59' 0"
40' 0"
74' 0"

PLATE V
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No. 519.
McGUIRE ON
IRON WORK OF DOME.



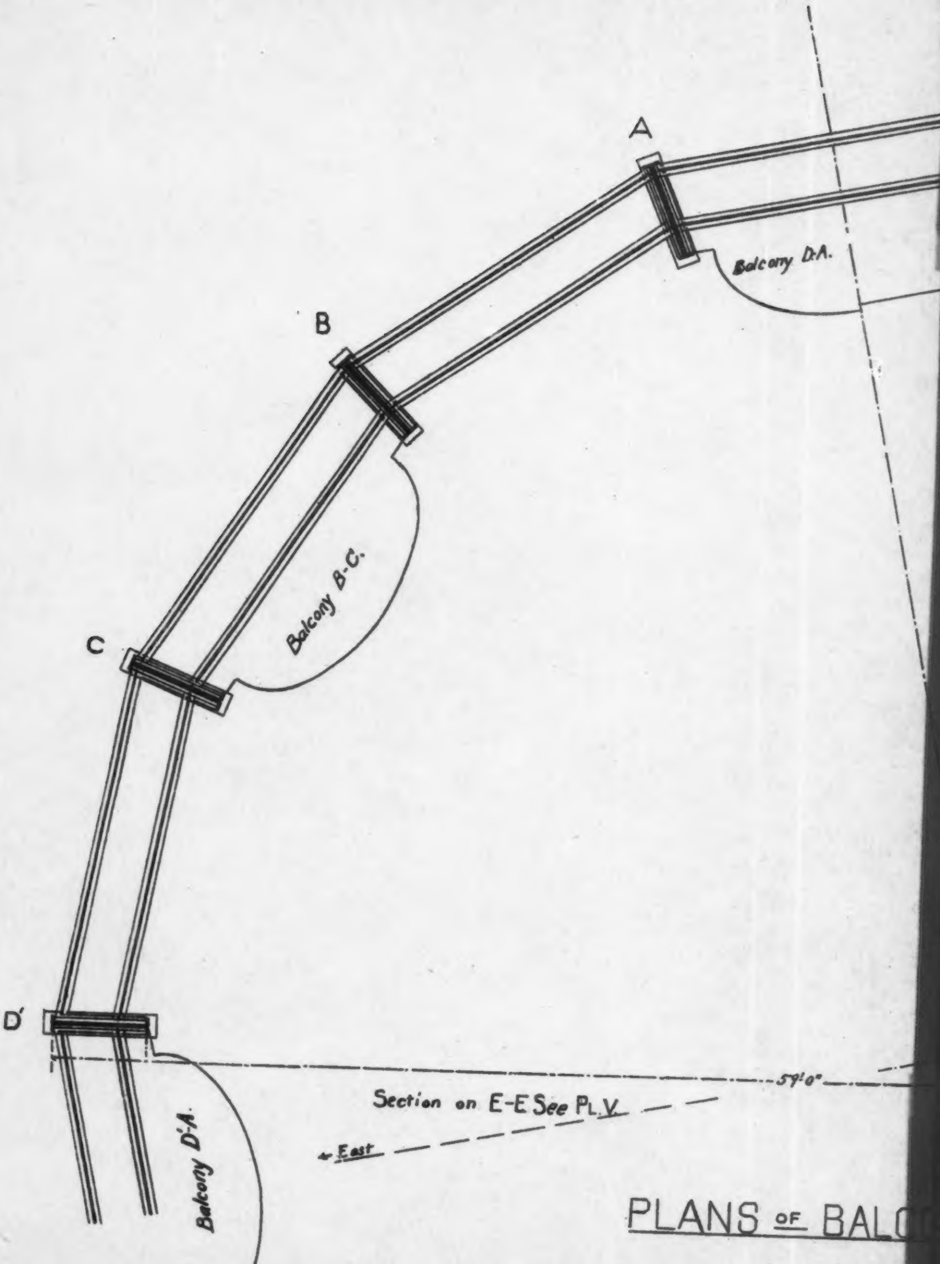
Wm Edbrooke
Supervising Architect,
TREASURY DEPARTMENT

Scale.
1' 3' 4' 8'

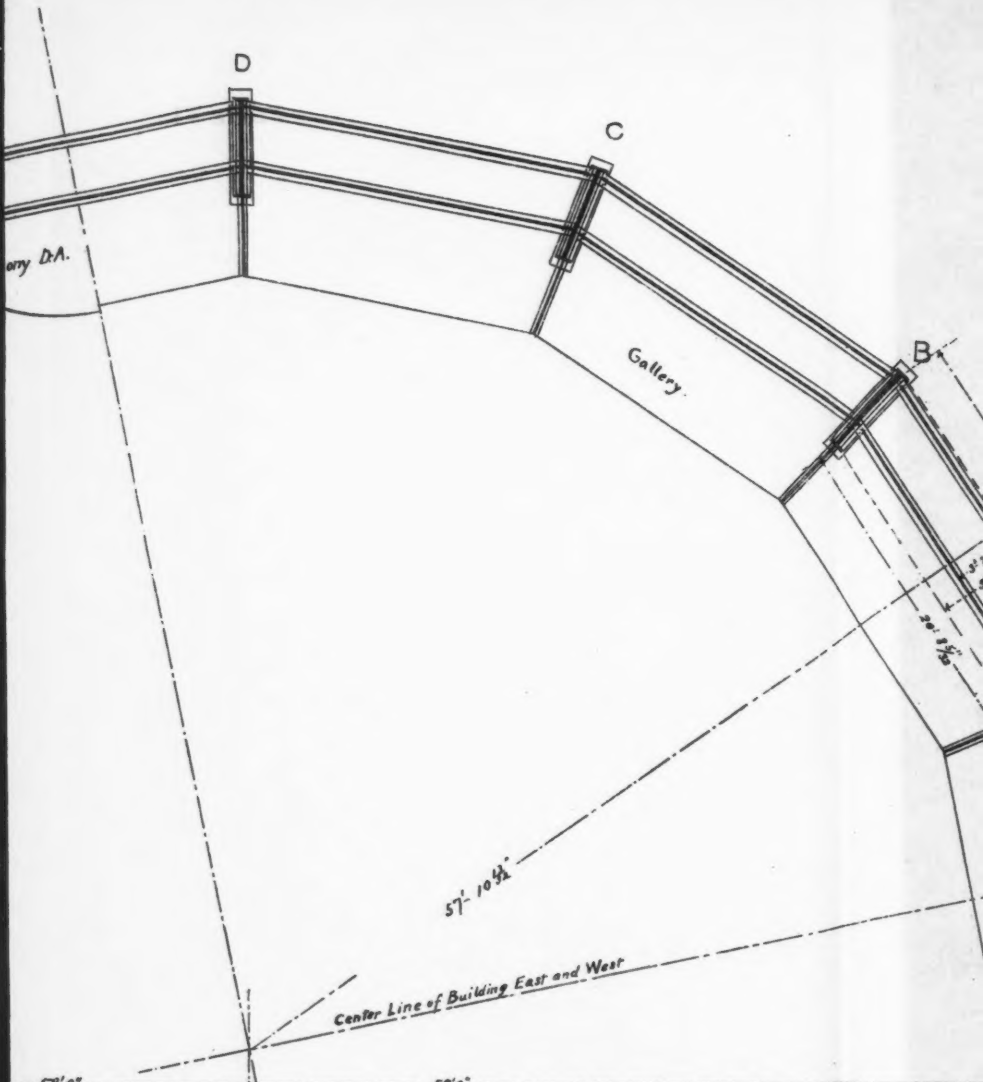
FRAMING OF DOME AND LANTERN.

Jas. C. McGuire

D'

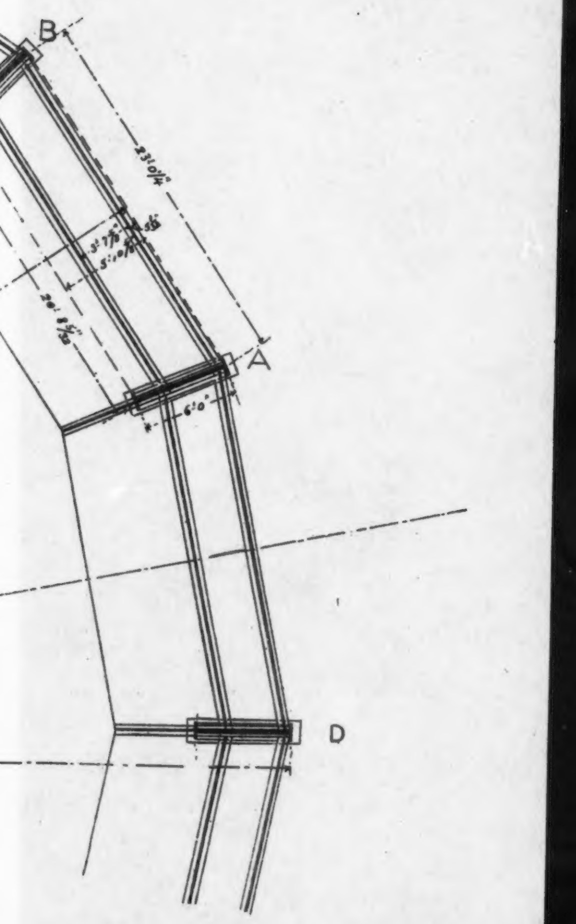


A
B
C
D′
Balcony D.A.
Balcony B-C.
Balcony D′-A.
59′0″
Section on E-E See PL.V.
East
PLANS OF BAL

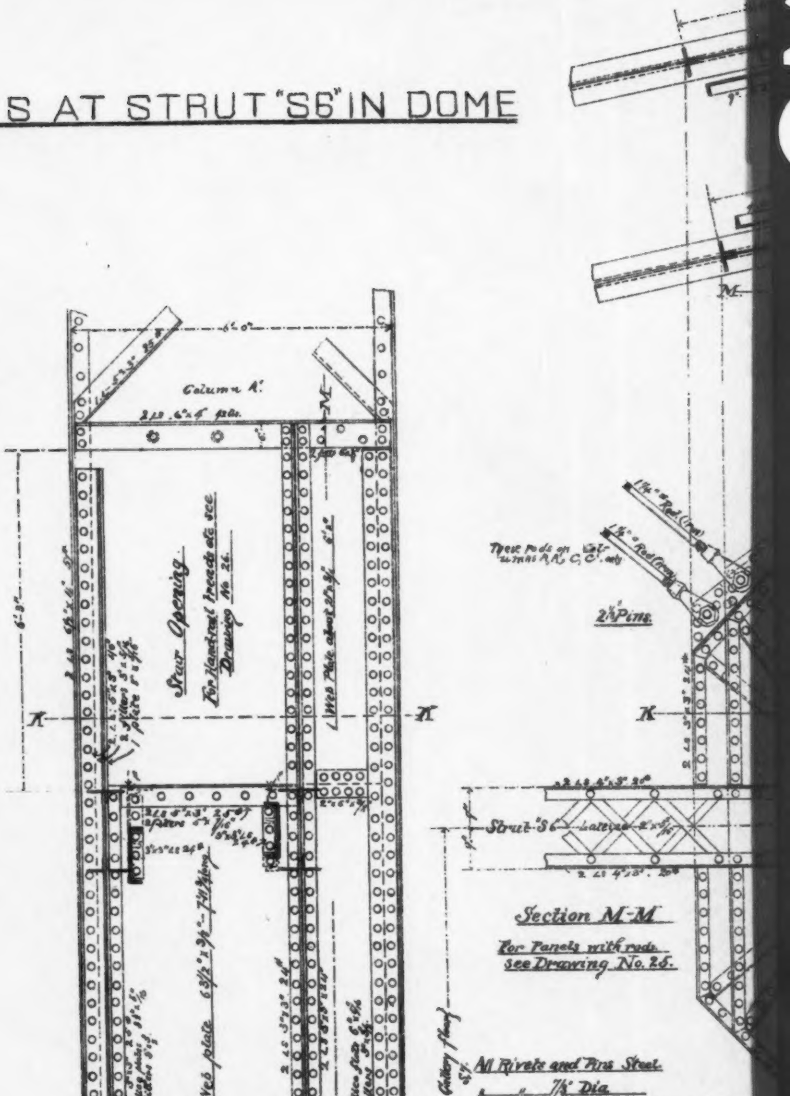


S OF BALCONYS AND GALLERY.

PLATE VI
TRANS. AM. SOC. CIV. ENG'RS.
VOL XXVI. No. 519.
McGUIRE ON
IRON WORK OF DOME.



DETAILS AT STRUT "S6" IN DOME



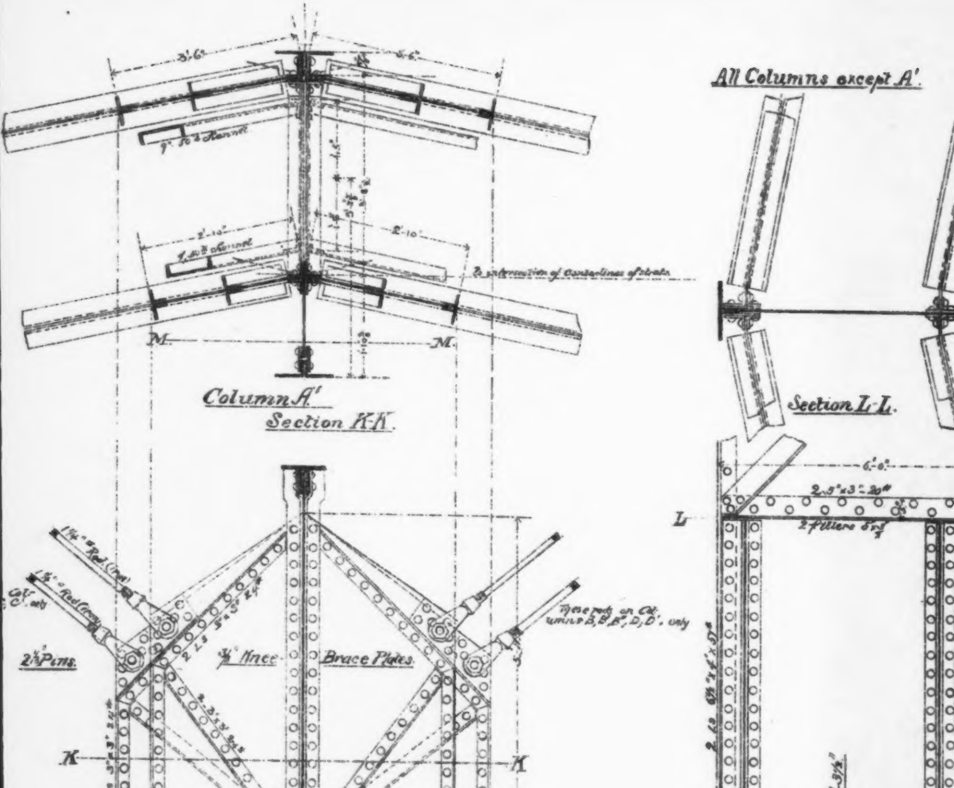
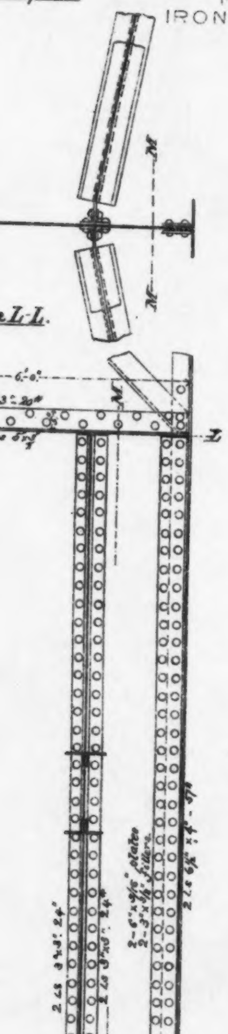

All Columns except A'.
Column A'
Section K-K.
Section L-L.
2½" Pins.
¾" Knee-Brace Plates.
Web Plate 63½" x ⅜" - 14'-3½"
M-M
with rods.
ing No. 25.
Pins Steel.
steel unless otherwise stated
Supervising Architect.
TREASURY DEPARTMENT.

PLATE VII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No. 519.
McGUIRE ON
IRON WORK OF DOME.



DETAILS OF FRAMING OF DOME.

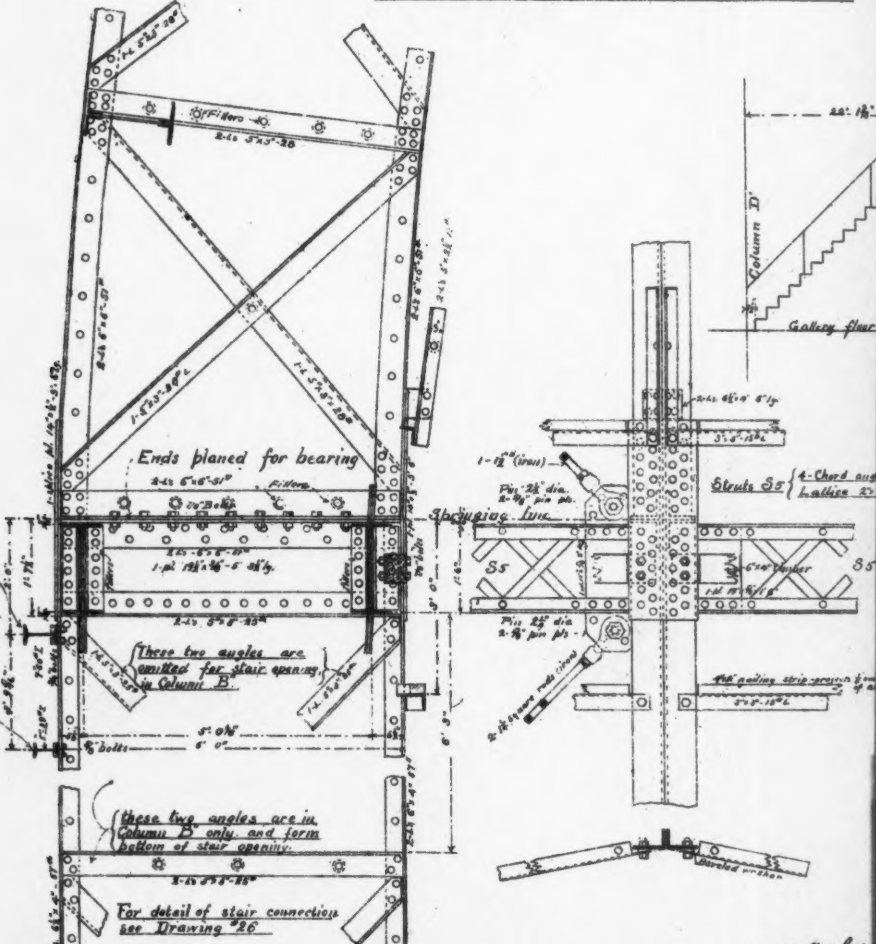
Scale 1' 1' 1' AND 1' 3' 4'

There is only one flight of stairs above Gallery.

Stairs are de...

DETAIL OF RIBS.

All rivets steel 7/8" dia. unless otherwise stated.
All material steel " " "



Jas. C. McSmith

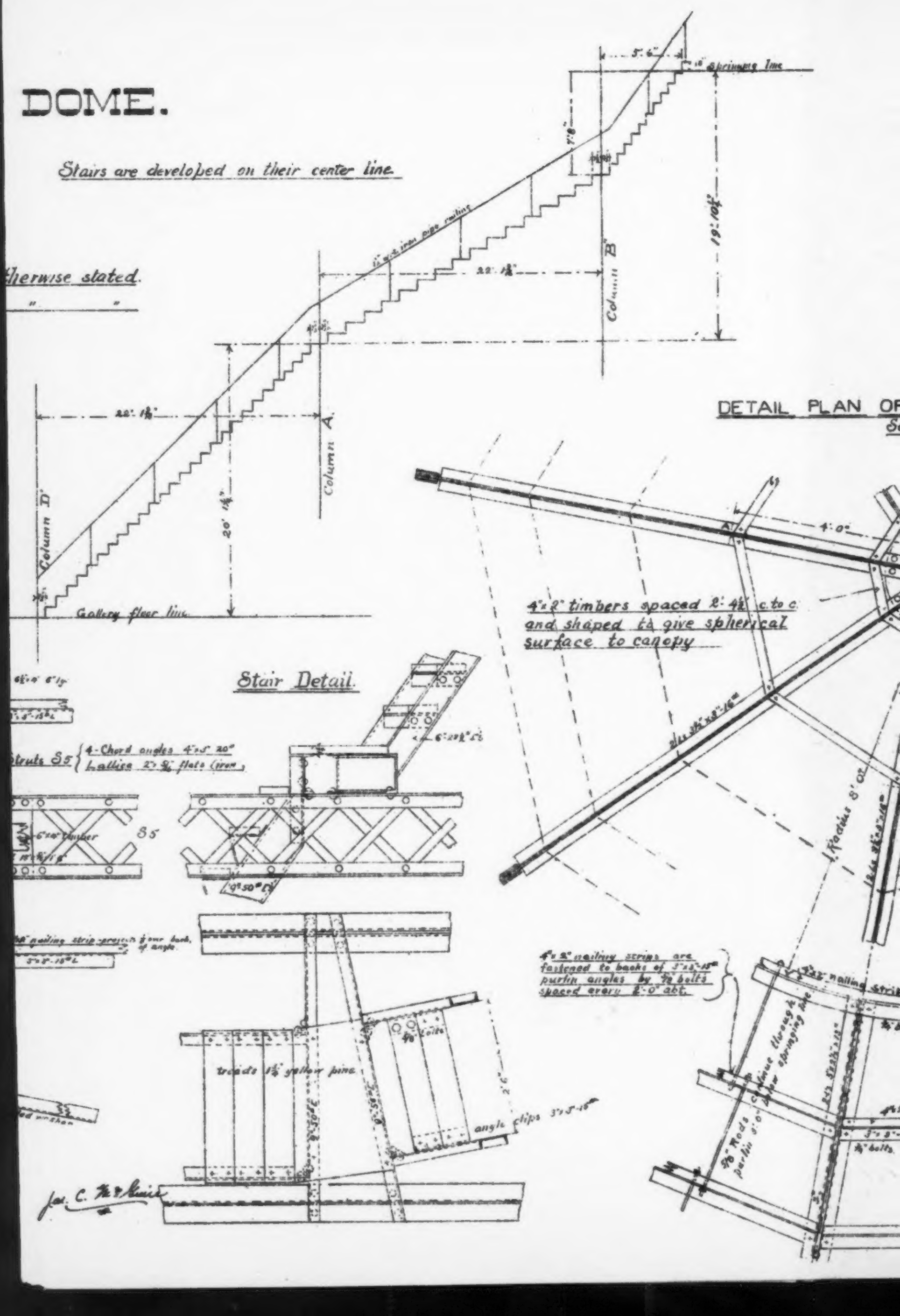

DOME.
Stairs are developed on their center line.
therwise stated.
Springing line
5' 6"
19' 10¼"
22' 1⅛"
Column B
Column A
Column D
20' 1¼"
Gallery floor line
DETAIL PLAN OF
4"×2" timbers spaced 2' 4½" c. to c. and shaped to give spherical surface to canopy
Stair Detail.
4'-0"
Radius 8' 0"
4"×2" nailing strips are fastened to backs of 3"×5"-15# purlin angles by ⅜" bolts spaced every 2'-0" abt.
treads 1½" yellow pine
angle clips
S5

PLATE VIII.
TRANS. AM. SOC. CIV. ENG'RS.
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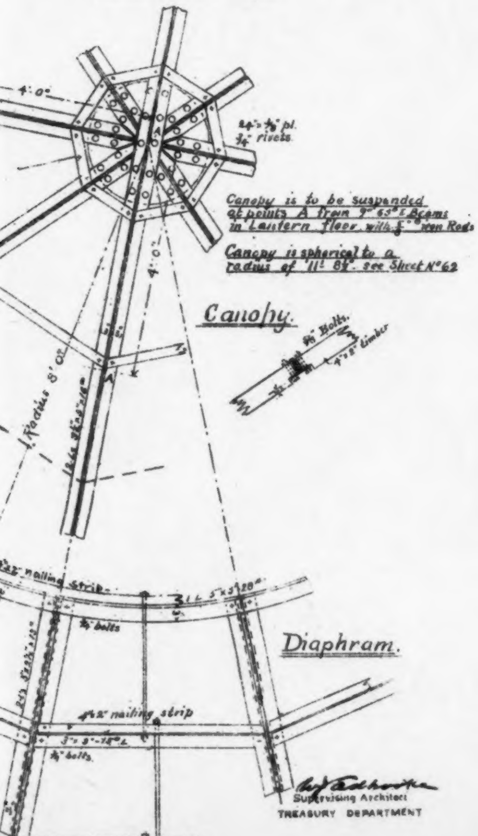
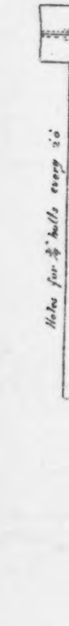
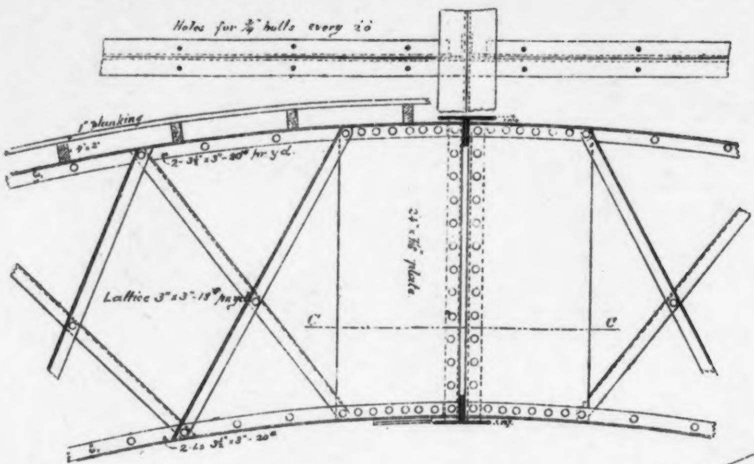
McGUIRE ON
IRON WORK OF DOME.

PLAN OF DIAPHRAM AND CANOPY.

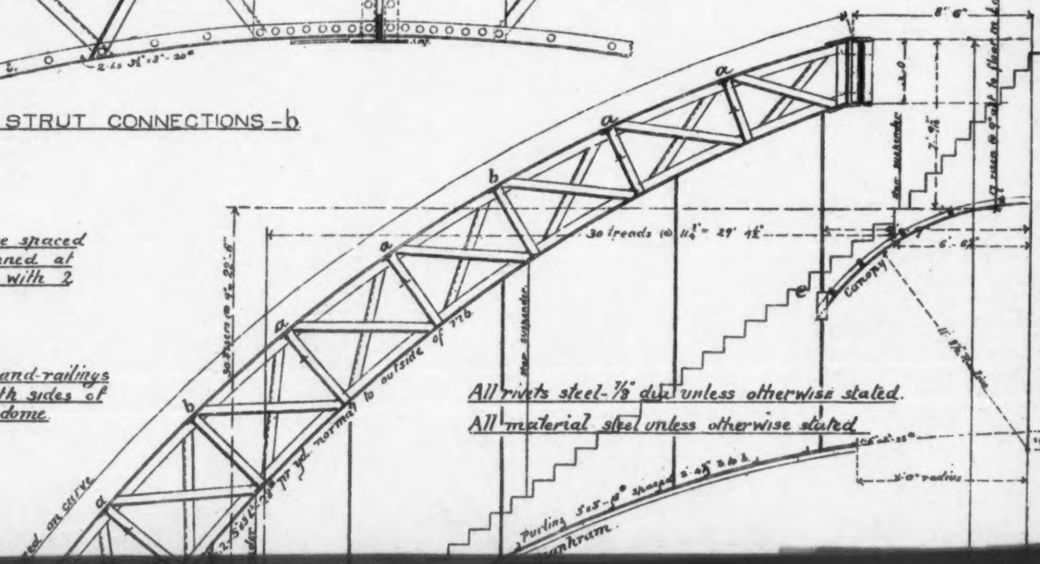
See Drawnig No 62.




Holes for ¾" bolts every 2'0"



DETAIL OF STRUT CONNECTIONS - b



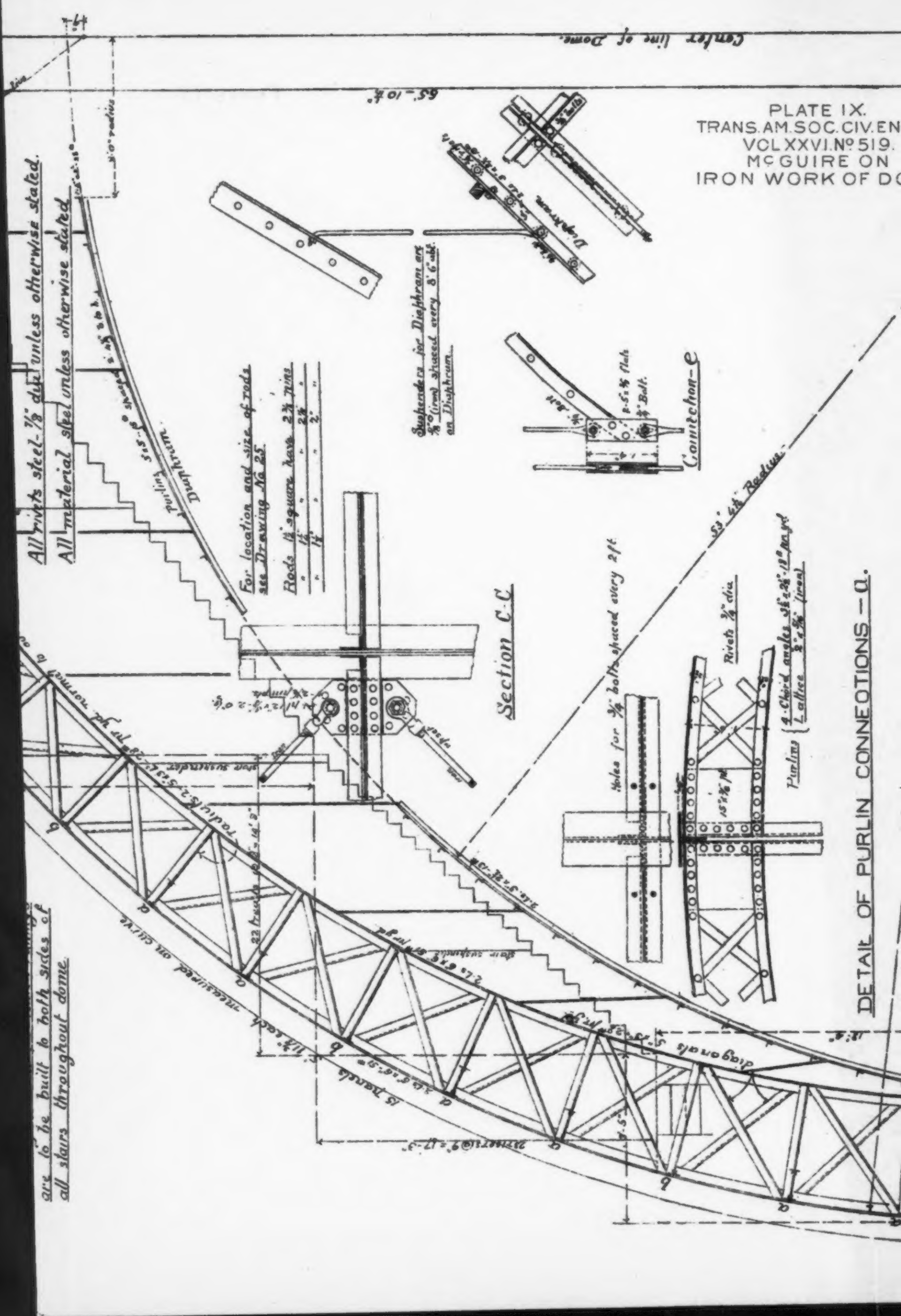
4"x2" Wood rafters are spaced every 2'0" and are fastened at every Strut and Purlin with 2 3/4" bolts.

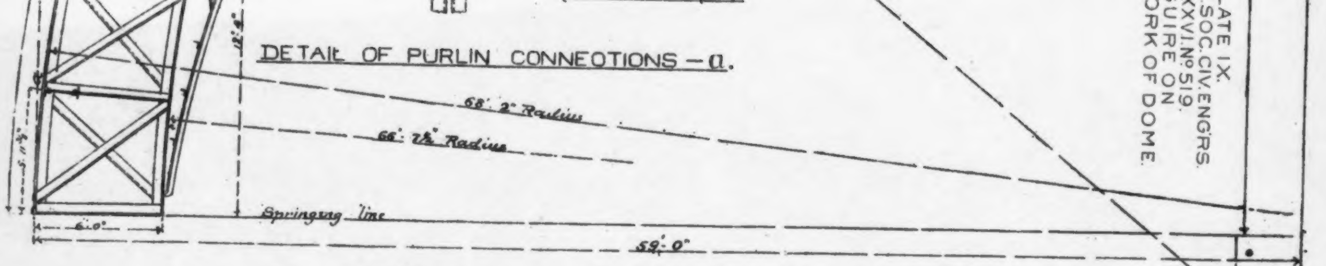
1½" wrought iron pipe hand-railings are to be built to both sides of all stairs throughout dome.

All rivets steel-7/8" dia. unless otherwise stated.

All material steel unless otherwise stated.

PLATE IX.
TRANS. AM. SOC. CIV. EN[GRS.]
VOL XXVI. Nº 519.
McGUIRE ON
IRON WORK OF DO[MES]





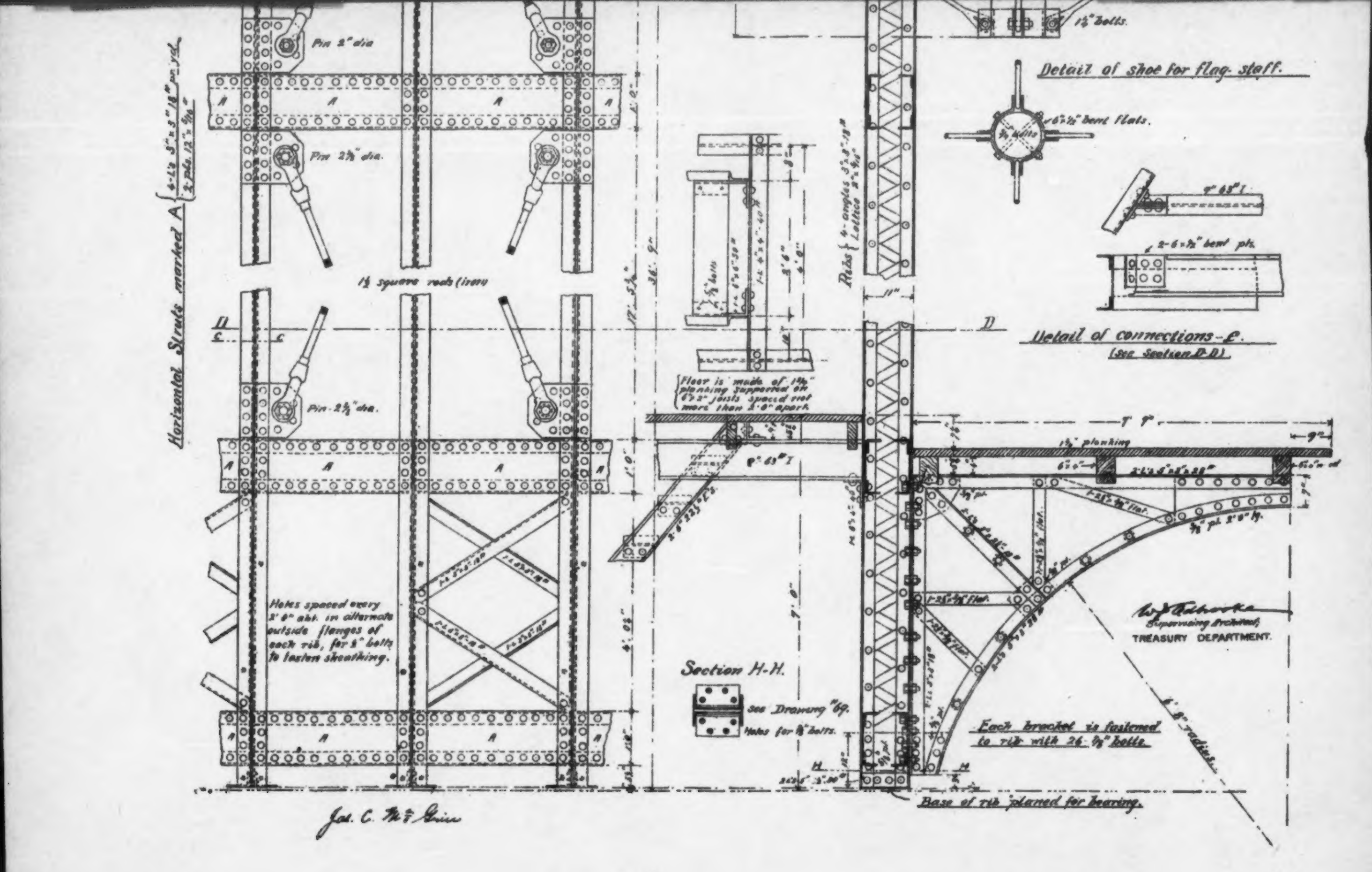
STEEL FRAMING IN DOME.

Scale 1' 2' 3' AND 1' 1' 1'

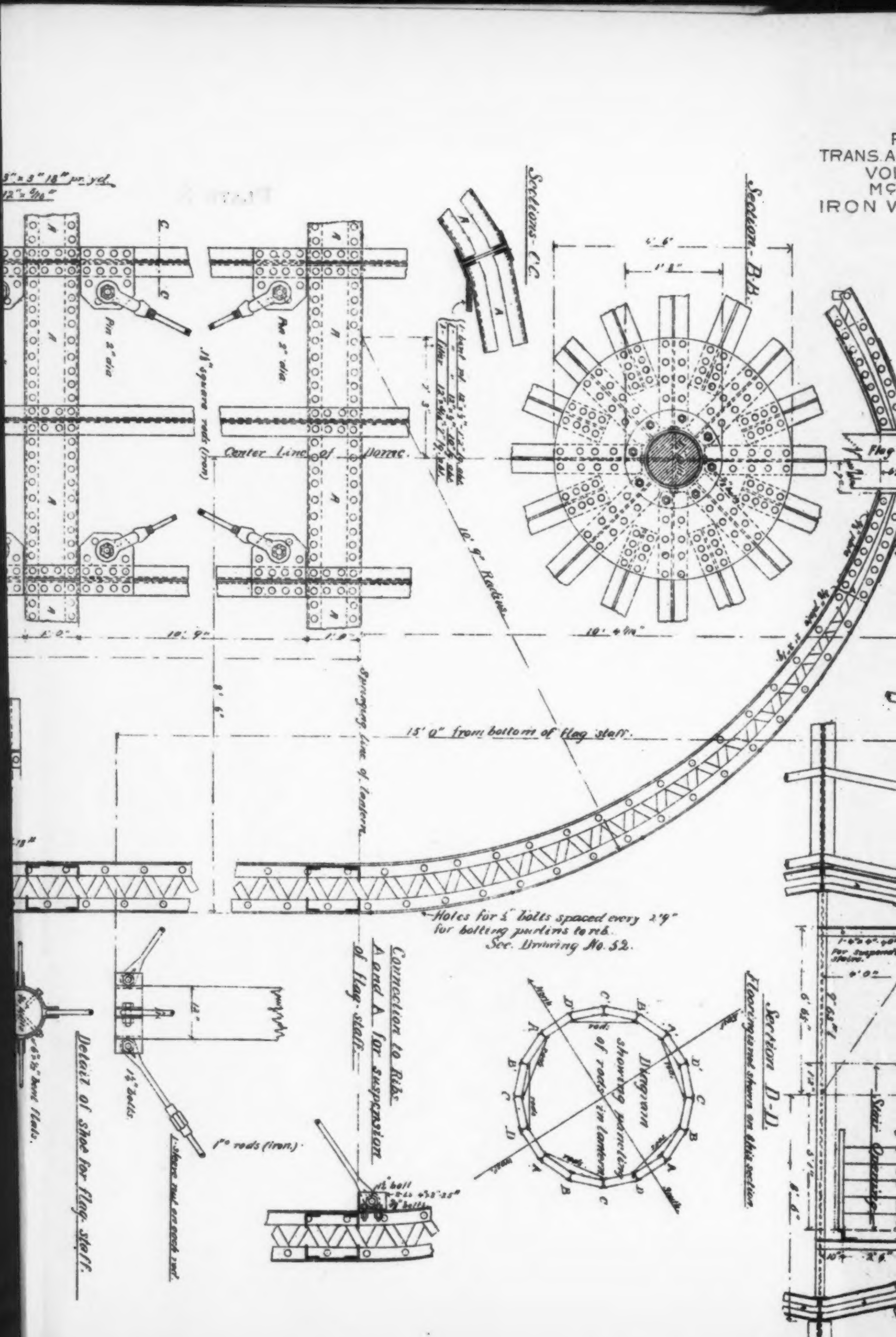
For other details see Drawing No. 29

Jas. C. McGuire

Supervising Architect.
TREASURY DEPARTMENT.



Horizontal Struts marked A
1½ square rods (iron)
Pin 2" dia.
Pin 2½" dia.
Holes spaced every 2' 6" abt. in alternate outside flanges of each rib, for ½" bolts to fasten sheathing.
Floor is made of 1½" planking supported on 6"x2" joists spaced not more than 2'-0" apart.
Section H-H.
See Drawing
Holes for ⅞" bolts.
Ribs { 4-angles
Lattice
Detail of shoe for flag staff.
bent flats.
Detail of connections-C.
(see Section D-D)
1½" planking
Each bracket is fastened to rib with 26-⅞" bolts
Base of rib planed for bearing.
radius.
Supervising Architect,
TREASURY DEPARTMENT.



TRANS.A
VO
M
IRON W
Sections-C.C.
Section-B.B.
Center Line of Dome.
10' 9" Radius.
15' 0" from bottom of Flag staff.
Springing line of lantern
Holes for 1" bolts spaced every 2'9"
for bolting purlins to rib.
See Drawing No. 52.
Connection to Ribs
A and A for suspension
of flag staff.
Detail of shoe for flag staff.
Diagram
showing paneling
of rods in lantern
Section D-D.
Flooring and stairs shown on this section.
Stair Opening

DETAILS OF FRAMING OF LANTERN.

PLATE X.
TRANS. AM. SOC. CIV. ENG'RS.
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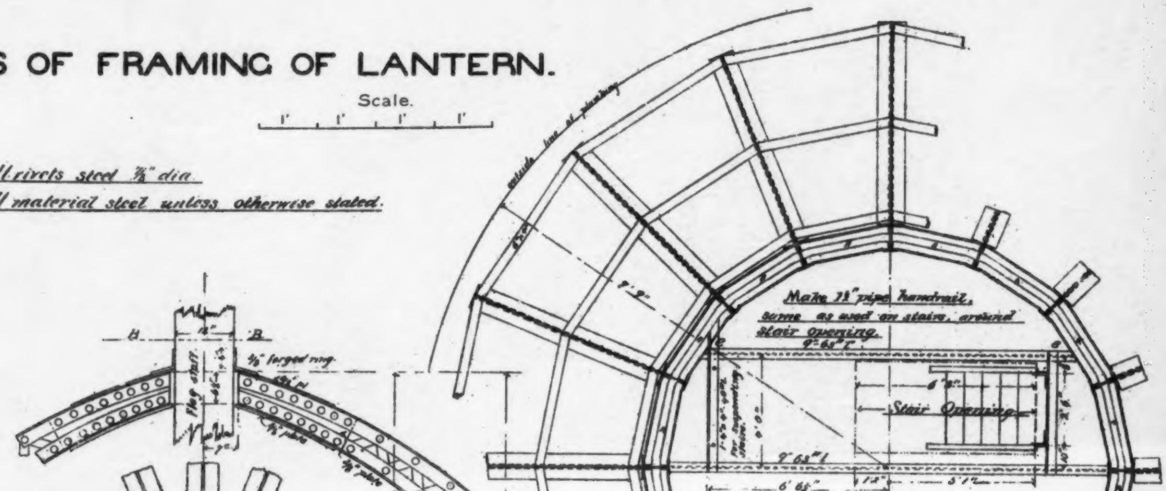
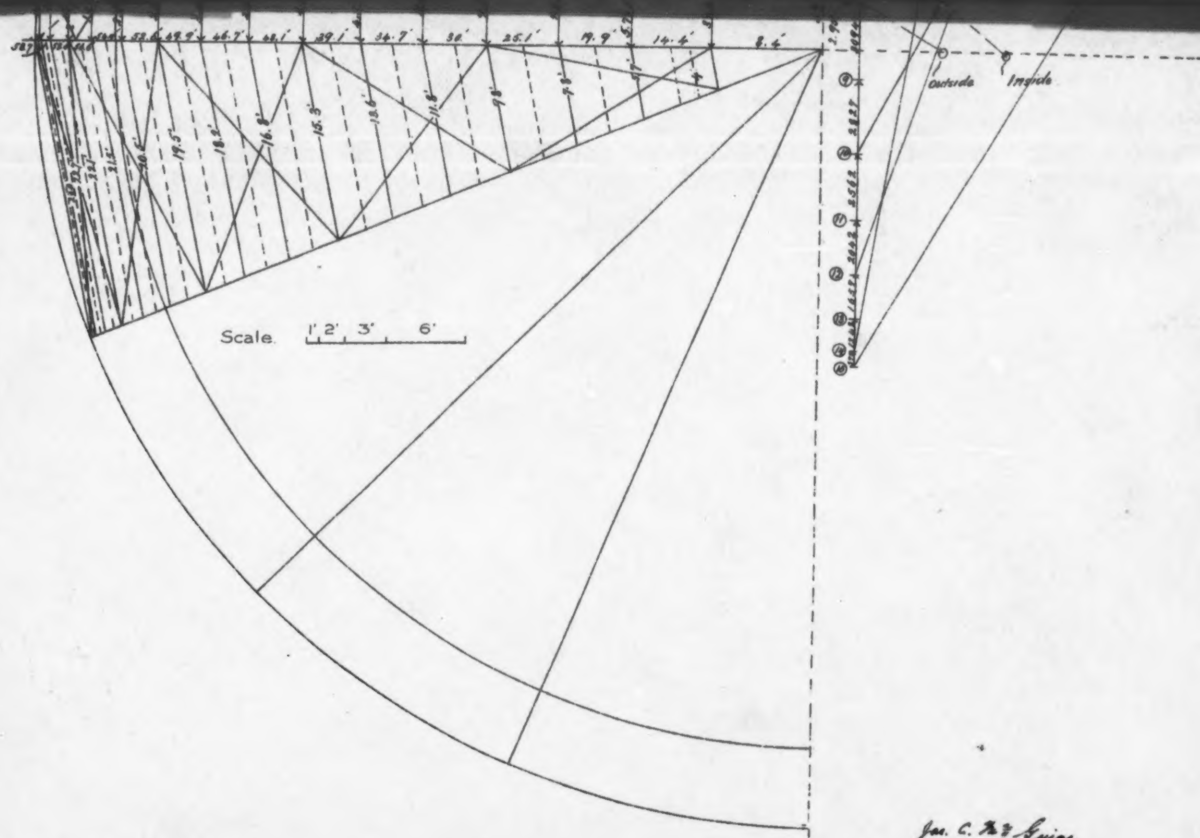
All rivets steel ⅞" dia.

All material steel unless otherwise stated.

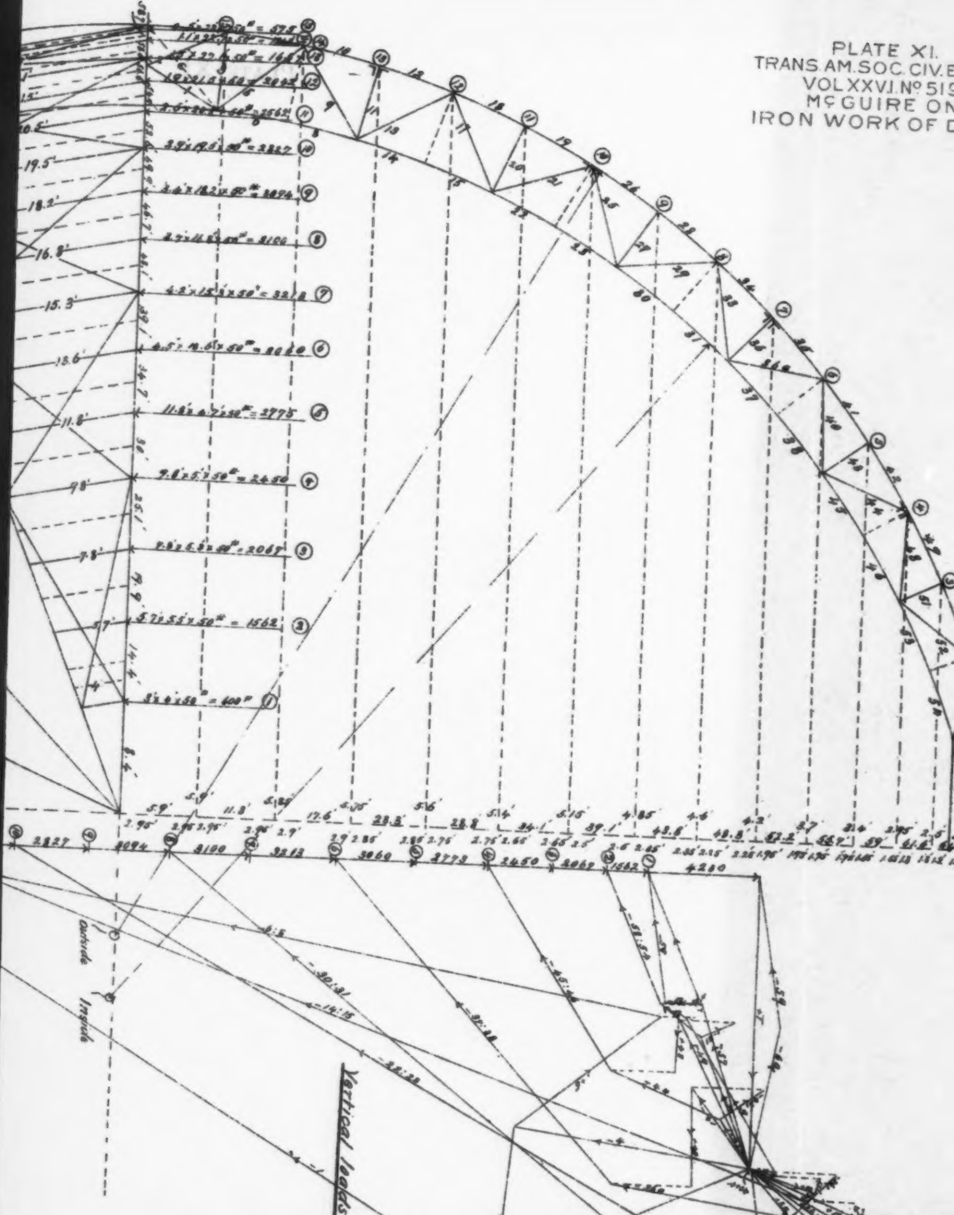




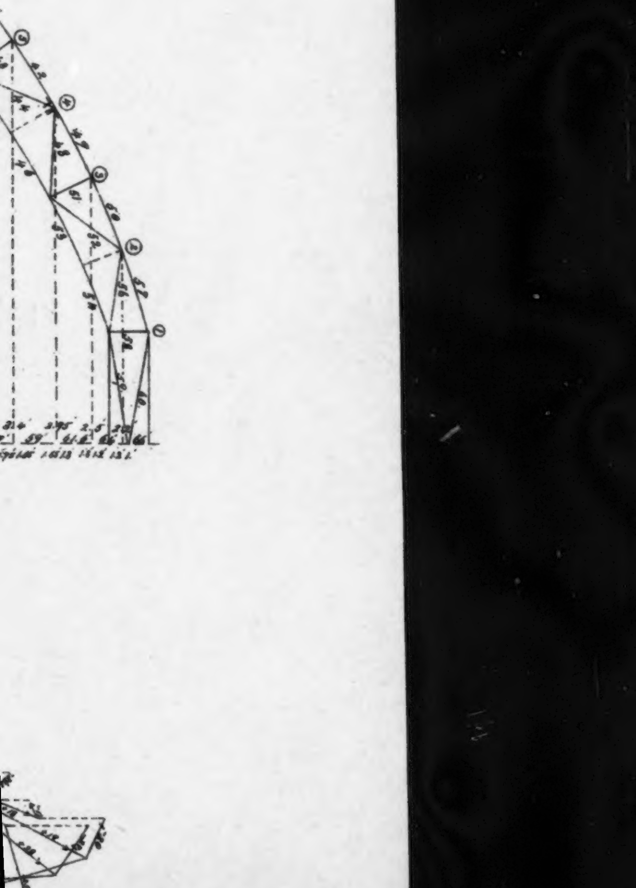
Jas. C. McGuire

STRAIN DIAGRAM.

PLATE XI.
TRANS. AM. SOC. CIV. E
VOL XXVI. Nº 51
McGUIRE ON
IRON WORK OF D



TE XI.
OC. CIV. ENG'RS.
VI. Nº 519.
IRE ON
RK OF DOME.



AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

520.

(Vol. XXVI.—January, 1892.)

ON THE HYDRAULICS OF THE HEMLOCK LAKE CONDUIT OF THE ROCHESTER, N. Y., WATER-WORKS.

By GEORGE W. RAFTER, M. Am. Soc. C. E.

WITH DISCUSSION.

The Rochester Water-works were made a dual system, involving a domestic supply by gravity from Hemlock Lake and a supply by direct pressure from the Genesee River, for the suppression of fires. Upon the completion of the line from Hemlock Lake to Rush Reservoir its designing engineers published its capacity under normal conditions, as 9 292 800 gallons in twenty-four hours. In the annual report of the Executive Board of the City of Rochester for the year 1876 may be found a discussion of the hydraulic questions involved, together with a theoretical demonstration, that the daily discharge of 9 292 800 gallons was in accordance with the more recent determinations as to the discharge of large conduits.

The source of the domestic water supply of the City of Rochester, Hemlock Lake, is 385.6 feet above the city datum, and distant, along the pipe line, about 29.3 miles. Mount Hope, the distributing reservoir, is

about 1.4 miles from the center of the city, and the normal water surface is 124.4 feet above the city datum. When filled to its normal depth of 15 feet, Mount Hope Reservoir stores 22 500 000 gallons of water. Rush Reservoir, intended chiefly for additional storage, is distant from Mount Hope 46 064 feet (8.72 miles) along the pipe line.* The normal water surface at Rush Reservoir is 117.4 feet above the normal water surface at Mount Hope, the depth in the Rush Reservoir being, at normal elevation, 18 feet. At this depth it stores 70 000 000 gallons. From Rush Reservoir to Hemlock Lake the distance is 101 261 feet (19.2 miles) along the pipe line,† and the mean low water surface of the lake is 143.8 feet above normal water surface at Rush Reservoir, or 385.6 feet above city datum as stated in the foregoing. Leading from Hemlock Lake toward Rush Reservoir (see profile) the first 50 776 feet of the conduit is 36-inch wrought-iron pipe, this portion of the line having been laid with a total fall of 21 feet or on a grade of 0.411 per 1 000 feet. The diameter for the balance of the distance from the end of the 36-inch wrought-iron pipe to Rush Reservoir is 24 inches, the material being partly wrought-iron pipe and partly cast-iron as defined in the following: (1) From the end of the 36-inch wrought-iron pipe 1 914 linear feet of 24-inch wrought-iron pipe; (2) 30 550 lineal feet of cast-iron; (3) 13 809 linear feet of wrought-iron pipe; (4) finally, 4 212 feet of cast-iron pipe to the face of the gate-house at Rush Reservoir. Adding the length for the continuation of the pipe line to the point of discharge in the bottom of the reservoir, gives a total of 5 222 feet. From the end of the 36-inch wrought-iron pipe to Rush Reservoir the grade is continuous, and taken to the end of the pipe in the discharge well it is to normal water surface at the rate of 2.26 feet per 1 000. Between Rush and Mount Hope Reservoirs the conduit is of 24-inch cast-iron pipe, with a grade, when reckoned from normal water surface of both reservoirs, of 2.51 per 1 000 feet.

In designing this pipe line the engineers considered it desirable to make two grades, forming thereby a compound conduit. The location actually adopted, however, involved a number of cuts, in order to keep the upper section (the 36-inch) down to the assumed grade of the line located, and at the several points where these cuts occur the actual position of the conduit is shown on the profile by a heavy line. At

* This is the distance as measured from face to face of gate-houses.

† Also measured from face to face of gate-houses.

points where the natural surface of the ground is below the assumed limiting pipe grade, the upper side of the pipe is merely below the surface of the ground far enough to insure safety from freezing; but inasmuch as the profile is on an exaggerated scale, it is obviously difficult to show the actual location of the pipe in relation to the ground surface at every point. In studying the profile it is sufficient to remember that at all points other than in the cuts where the actual position of the pipe is shown, as already described, the pipe line is, generally speaking, nearly parallel to the surface of the ground and from 3 to 5 feet below it, slight variations having been made in order to ease off curves at places where the natural surface changes abruptly. The dotted line connecting the heavy portions indicating the pipe line in the cuts, may be taken as showing where the top of the pipe would be for the whole distance, provided it were laid *in train* to a continuous grade, said dotted line being of course parallel to the theoretical grade line along the center of the pipe and 1.5 feet above it for the 36-inch section. From air valve 53 to Rush Reservoir the conduit is, as indicated on the profile, 24 inches in diameter, and the approximate position of the hydraulic grade, when the conditions of delivery are such as to give the lowest possible position of the hydraulic grade, is shown by a dotted line.

Obviously the conditions which determine this position of the hydraulic grade are, that the elevation of the lake surface be such as to just run the 36-inch section full at the upper end, in which case the hydraulic conditions for the portions of the 36-inch conduit which are laid to a pipe grade in the cuts would be expressed by saying a full pipe in train; the hydraulic grade of the 36-inch, under these conditions, corresponding to the pipe grade, provided the resistance is the same throughout the whole extent of the 36-inch pipe. The approximate position of the hydraulic grade at the time of making the following described tests is shown on the profile by broken line, thus: ——— - - ——— - - ——— - - (Plate XII).

The foregoing gives rather briefly the main points in the hydraulics of this pipe line, and we may now proceed to a brief discussion of some of the recent determinations of the actual delivery of this pipe as made by the present writer during the last season. Before doing this, however, it is proper to state that when the Rochester water-works were considered finished in 1876, the population of the city was about 82 000. In 1880 it was 89 000, and in 1890 the census returns show 133 896. This considerable increase in population has naturally led to a large use of water, and

for the past three seasons the storage has been so drawn upon as to render the situation at times somewhat alarming. On the 1st of May, 1890, the storage at Rush Reservoir was about 44 000 000 gallons. As warm weather came on in June this was drawn upon at the rate of from 1 000 000 to 2 000 000 gallons per day, and at this rate of decrease it could be only a very small number of days before the city would be without any storage at all.

Mr. Brush, in the discussion of a paper on the "Fresh Water Algæ," etc., which the author had the honor to read before the Society about two years ago, has vividly described the excitement prevailing in Hoboken at a time when the water supply of that city became seriously affected with bad tastes and odors. His description is quite tame in comparison with the hubbub prevailing in Rochester in 1890 at the prospect of a serious water famine in the middle of the summer. The city papers were filled with editorials and communications from citizens, and at the height of the excitement the Executive Board of the city, as being charged by law with the care and maintenance of the water-works, directed the present writer to take such measures as would, if possible, avert a water famine at that time. The language of the resolution of the Executive Board directing such measures was exceedingly strong, and under its provisions full authority was given to adopt any precautions and make any expenditures necessary to produce the desired result.

During all this time of popular discussion, everything said and written had been on the supposition that the Hemlock Lake conduit was delivering at the rate indicated by the measurement made soon after its completion in 1876, or, at the rate, under normal conditions, of about 9 292 800 gallons in twenty-four hours. It appeared to the author, however, that the proper basis of any restrictive measures would be a clear idea of the present delivery, and accordingly, his first step was in the direction of determining definitely what quantity was being delivered at that time. For this purpose four measurements were made, and as the mean of the four it was ascertained that the actual delivery, including allowance for evaporation at Rush Reservoir and other allowances, was at the rate of 6 742 000 gallons per day, taken in the discussion for even figures at 6 700 000 gallons, a quantity representing approximately the net delivery. Relative to these measurements it may be stated that the determination of the quantity of flow was obtained by observing the height to which the water rose in Rush Reservoir in a

given period of time. The dimensions of the reservoir being known, the daily inflow is obtained by a simple computation. Three of the four observations, of which the mean is given as 6 742 000 gallons in twenty-four hours, were for a period of twelve hours and one for a period of twenty-four hours.

At the time of making these measurements the surface of Hemlock Lake was considerably above normal surface, while the water surface at Rush Reservoir, into which the measured delivery took place, was several feet below normal elevation, the difference due to such departure from the normal being sufficient, if the conduit were in proper hydraulic condition, to produce a delivery of about 9 700 000 gallons in twenty-four hours instead of the 6 700 000 gallons which was actually found to exist; that is to say, the delivery was about 3 000 000 short of its capacity as stated in 1876.

In October a further measurement of the discharge was made by E. Kuichling, M. Am. Soc. C. E., for a period of seven hours and the foregoing results verified; the flow at that time being, with liberal allowance for evaporation, percolation, etc., at the rate of a trifle over 7 000 000 gallons per day. The author's own measurements are believed to be accurate within limits of 2 or 3 per cent. The difference thus found to exist between the actual delivery at the present time and the delivery as stated in 1876 is so exceedingly marked that the author has concluded a brief discussion of the hydraulic questions involved, together with a short statement of some further investigation, undertaken with a view of determining why the falling off should be so great, would be of interest to the Society, and this paper is an attempt to briefly present the same for consideration and discussion. The restrictive measures designed and successfully applied will be described in another paper.

The question of actual delivery being settled, the Executive Board further directed the author to make an investigation with a view of determining the reason for the considerable loss in delivering capacity of the conduit, and for such work the numerous air valves along the line offered convenient points of attachment for the application of piezometers. Moreover, for the 36-inch section the vertical distance from the surface of the ground to the hydraulic grade line was not so great but that actual piezometer heights could be measured by setting up tubes of wrought-iron pipe and taking the elevation of the top of the piezometric column by direct instrumental observation. For the 36-inch section and that

portion of the 24-inch above air-valve 48, the determinations were all made by direct observation of the height of the piezometric column as indicated, while for the balance of the line the determinations were made by the use of pressure gauges. As preliminary to the work of determining the height of the piezometric column at the various air valves along the conduit line the levels were rerun from Hemlock Lake to Rush Reservoir and new bench marks established at or near each air valve. For this work two levelers were employed, each working independent of the other. The conditions expressed in the instructions to them were that their work must agree at any given bench mark within 0.02 of a foot, or failing to agree within that limit, the work was to be rerun until this limit of accuracy was reached. The greatest variation on any bench mark is 0.015 feet, and this was secured, generally speaking, without rerunning the work. What this represents in the way of care on the part of the levelers may be inferred from the character of the ground as indicated by the profile.

In taking the heights of the columns at the air valves, the stand pipe was extended vertically upward with wrought-iron pipe of the same size, this being 2 inches in the case of one pattern of air valve and three and a half in another. After so extending the stand pipe temporarily, the valve was opened and the column of water allowed to rise to its proper piezometric height; and after waiting a few minutes the height of water surface was determined by measurement to a point previously determined instrumentally on the air valve box below. In a few cases where the piezometric height left the top of the water column below the surface of the ground, the measurement was taken from instrumentally determined points down to the water surface rather than up. The location of points where this condition occurred is shown on the profile (Plate XII). The observations as to height of piezometric column were all made by two independent observers, recorded by each in his own note-book, and compared only after the necessary numerical computations for the elevation of water surface in the tube had been made. On that portion of the line where the distance from the surface of the ground to the hydraulic grade line is too great to admit of the application of tubes, and consequently the direct measurement of the actual height of column, pressure gauges were substituted as already noted. For this purpose two gauges were attached to each air valve at the same time, and allowed to remain for half an hour. The elevations of the centers of the gauges were instru-

mentally determined in a manner similar to that previously described for the height of piezometric column, and likewise every measurement and reading of gauge was checked by two observers working independently.

From data so derived the following table has been constructed:

TABLE No. 1.

SHOWING LOCATION OF AIR VALVES ON THE PRESENT CONDUIT OF THE ROCHESTER WATER-WORKS, AND THE HYDRAULIC GRADES BETWEEN SAID VALVES AS ACTUALLY EXISTING IN JULY AND AUGUST, 1890.

Number of air valve.	Station.	Distance in feet.	Elevation of hydraulic grade.	Hydraulic gradient, rate per 1 000 feet.
Well-house.	0	0	387.55	
91........	91x98	9 198	383.49	0.44
90........	98x21	623		
89........	106x12	791		
88........	114x30	818	382.75	0.33
87........	120x06	576	382.42	0.57
86........	128x20	814		
85........	132x98	478		
84........	139x83	685		
83........	150x08	1 025		
82........	161x45	1 137		
81........	165x33	388		
80........	171x20	587		
79........	184x15	1 295	379.48	0.46
78........	191x32	717	379.20	0.39
77........	200x92	960	378.81	0.40
76........	220x37	1 945	377.97	0.43
75........	230x87	1 050	377.51	0.44
74........	258x75	2 788	375.94	0.56
73........	266x06	731	375.74	0.27
72........	278x17	1 211	375.24	0.41
71........	281x19	302	375.13	0.38
70........	292x51	1 132	374.64	0.43
69........	313x17	2 066	373.71	0.46
68........	323x45	1 028	373.18	0.51
67........	332x52	907	372.65	0.58
66........	343x68.	1 116	372.29	0.32
65........	359x78	1 610		
64........	380x38	2 060	370.88	0.38
63........	391x08	1 070	370.39	0.47
62........	406x26	1 518	369.65	0.48
61........	422x10	1 584	369.00	0.41
60........	428x62	652	368.36	0.98
59........	441x34	1 272	367.62	0.57
58........	463x70	2 236	366.61	0.45
57........	470x70	700	366.28	0.47
56........	486x15	1 545	365.53	0.48
55........	489x09	294	365.33	0.67
54........	497x03	794	365.08	0.31
53........	508x19	1 116	364.65	0.38
52........	527x20	1 901	357.37	3.83
51........	536x58	938	355.18	2.33
50........	545x02	844	353.35	2.17
49........	562x09	1 707	349.57	2.21
48........	569x46	737	347.94	2.21
47........	591x41	2 195	343.55	1.99
46........	610x36	1 895	338.40	2.71
45........	615x14	478	337.78	1.29
44........	660x38	4 524	327.35	2.30
43........	662x35	197		
42........	677x10	1 475	323.72	2.17
41........	693x23	1 613	320.03	2.28
40........	699x78	655	319.05	1.50
39........	716x35	1 657	316.05	1.81
38........	726x16	981	311.81	3.03
37........	741x80	1 564	309.19	1.67
36........	787x63	4 583	{ 300.51 305 20	1.89
35........	828x57	4 094	298.47	1.64
34........	849x13	2 056	292.38	2.96
33........	856x23	710	288.18	5.91
32........	867x33	1 110	284.45	3.36
31........	870x97	364	283.10	3.71
30........	882x40	1 143	279.58	3.08
29........	897x91	1 551	272.91	4.30
28........	922x37	2 446	265.69	2.95
27........	928x42	605	263.65	3.37
26........	948x55	2 013	256.07	3.76
25........	954x54	599	254.62	2.42
24........	984x04	2 950	245.31	3.15
23........	1 002x67	1 863	241.79	1.89
Reservoir.	....	......	236.77	

The foregoing Table No. 1, gives the elevation of the hydraulic gradient at nearly all the air valves, and the variation in the rate between the different valves. By way of classifying these variations as to the kind of material of which the pipe line is composed, Table No. 2 was constructed, showing the rate of hydraulic gradient in the wrought-iron and cast-iron sections separately. The air valves, however, are not located at the ends of the different sections, and per consequence sections of wrought-iron lap short distances into cast and *vice versa*, the amount of such lapping being determined by reference to the profile in connection with the column of remarks in Table No. 2.

In reference to these grades for short distances, it may be remarked, that by repeating the tests on different days it was observed that slight variations from the previous results were in some instances found. If, however, we consider long stretches of pipe, as has been done in Table No. 2, the error incident to the shorter distances is thereby eliminated, and we reach results which may be accepted as representing the real state of the case within a small limit of possible error.

TABLE No. 2.

Air Valve.	Station.	Distance in Feet.	Elevation of Hydraulic Grade.	Rate of Hydraulic Gradient per 1 000 Feet.	Remarks.
Well-house at Lake..	0	0	387.55	....	
					36-inch wrought-iron pipe.
53	508 + 19	50 819	364.65	0.45	
					24-inch wrought-iron pipe.
52	527 + 20	1 901	357.37	3.83	
					14 lineal feet 24-inch wrought-iron pipe. 30 123 lineal feet 24-inch cast-iron pipe.
35	828 + 57	30 137	298.47	1.95	30 137 = total between valves.
					427 lineal feet 24-inch cast-iron pipe. 13 809 lineal feet 24-inch wrought-iron pipe. 1 311 lineal feet 24-inch cast-iron pipe.
24	984 + 04	15 547	245.31	3.43	15 547 = total between valves.
34	849 + 13	....	292.38	....	24-inch wrought-iron pipe.
25	954 + 54	10 541	254.62	3.58	

In order to compare the results of these tests, we will assume that, for the observed discharge, the rate of hydraulic gradient in the 36-inch pipe ought not to exceed 0.3 feet per 1 000 feet, while in the 24-inch it should be 1.75 feet per 1 000, these quantities representing fairly the results of observation on clean pipes as determined by different experimenters. Making the comparison, a number of important facts are shown to exist, as for instance:

First.—That the average rate of hydraulic grade in the 36-inch pipe is 50 per cent. greater than it should be for clean pipe with the observed discharge.

Second.—That in the section of 24-inch wrought-iron pipe, between air valves 53 and 52, the rate of hydraulic gradient is 120 per cent. in excess of the normal with the observed discharge.

Third.—That in the section of 24-inch pipe, between air valves 52 and 35 (30 137 feet in length, of which 30 123 feet is cast-iron), the rate of grade is only slightly in excess of the normal.

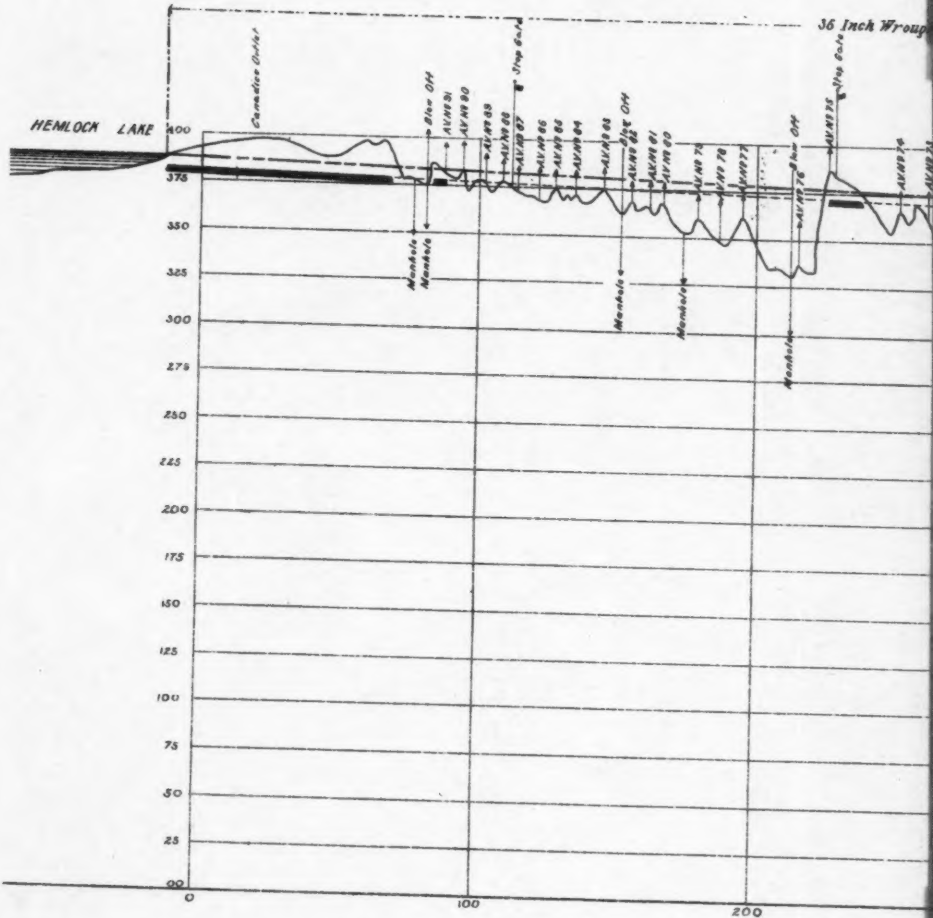
Fourth.—That in the section from air valve 34 to 25, all 24-inch wrought-iron, the rate of grade is over 100 per cent. in excess of the normal for the observed discharge.

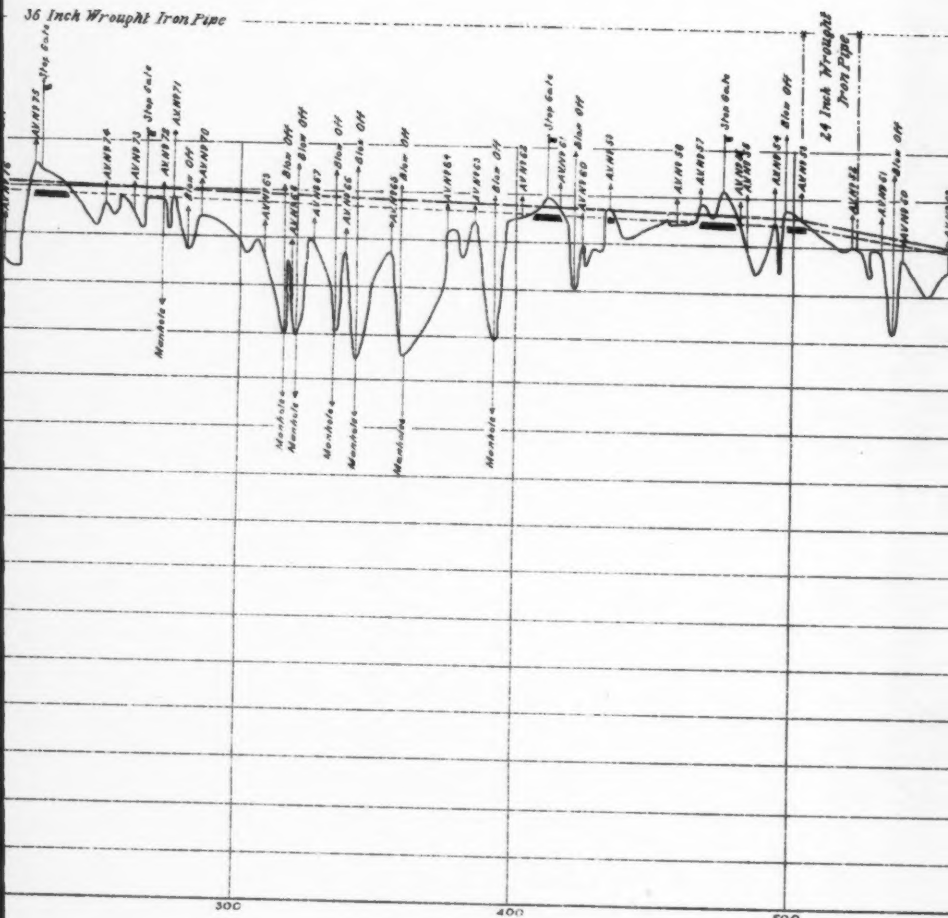
Fifth.—From all of the foregoing it is further concluded that the excessive resistance prevailing in this pipe-line at the present time is mostly confined to the wrought-iron section; the excess in the cast-iron being, generally speaking, only such as may be reasonably expected in pipe a long time in use.

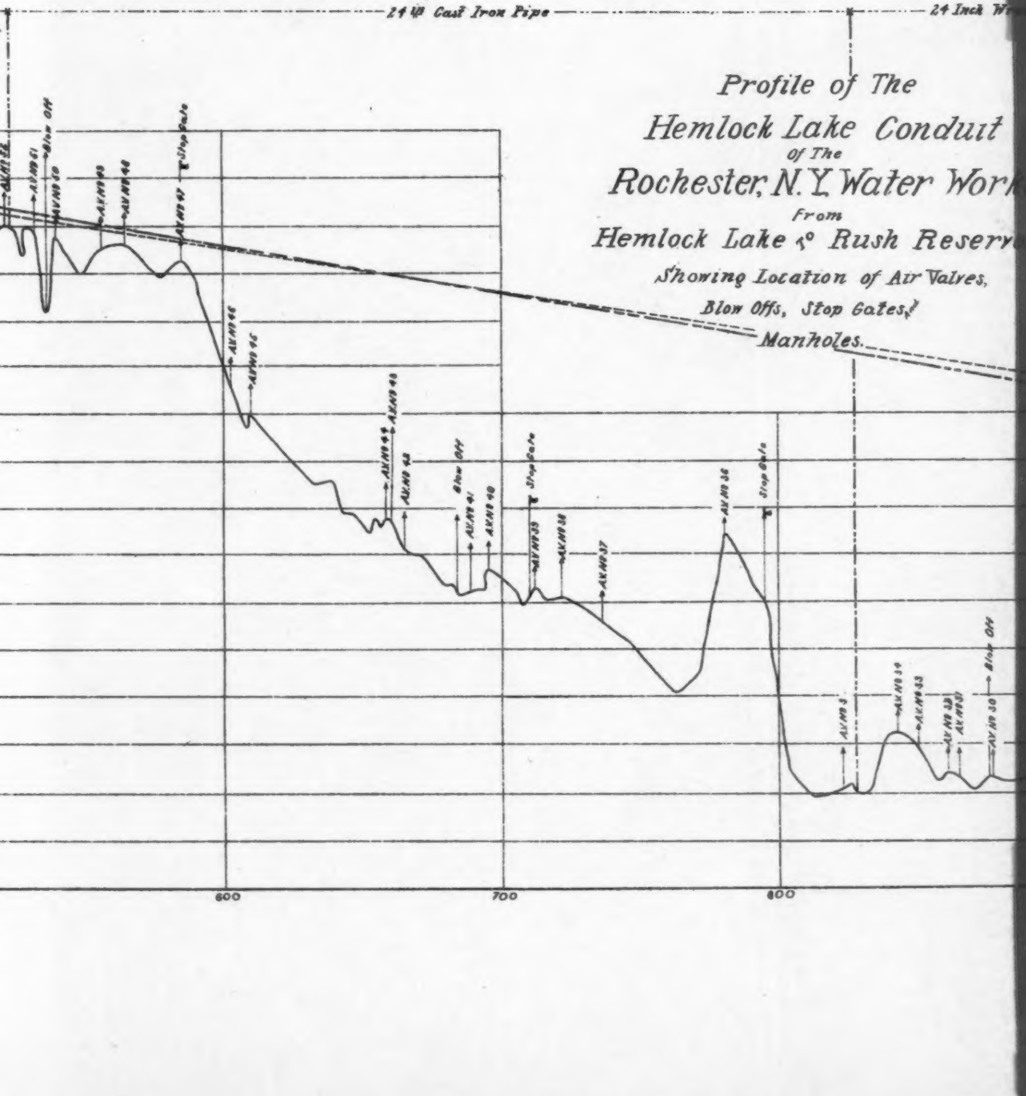
In the absence of a thorough examination of the interior of the pipe, positive statements as to the exact cause of the trouble cannot be made, though it is not difficult with the information now at hand to form a clear idea of the location of the difficulty. An inspection of Table No. 1 shows the amount of variation in the rate of grade at different points. Occasionally the grade is substantially what it should be, as between air valves 67 and 66, where for a distance of 1 116 feet it is 0.32. At a number of places, however, the rate is much higher than the normal, and it has been positively stated that at these places work of an unsatisfactory character was done in the original construction. An inspection of the reservoir record indicates that the present flow has probably not been exceeded for several years, but the lack of completeness of the record renders it impossible to say what the changes have been. The present flow is, however, so much less than the reputed capacity of the con-

duit, that, in the opinion of the author, the Rochester conduit cannot be taken as proving the correctness of the modern views as to the value of C to be used in the formula $V = C\sqrt{RS}$ when pipes of large diameter and long lengths are under consideration.

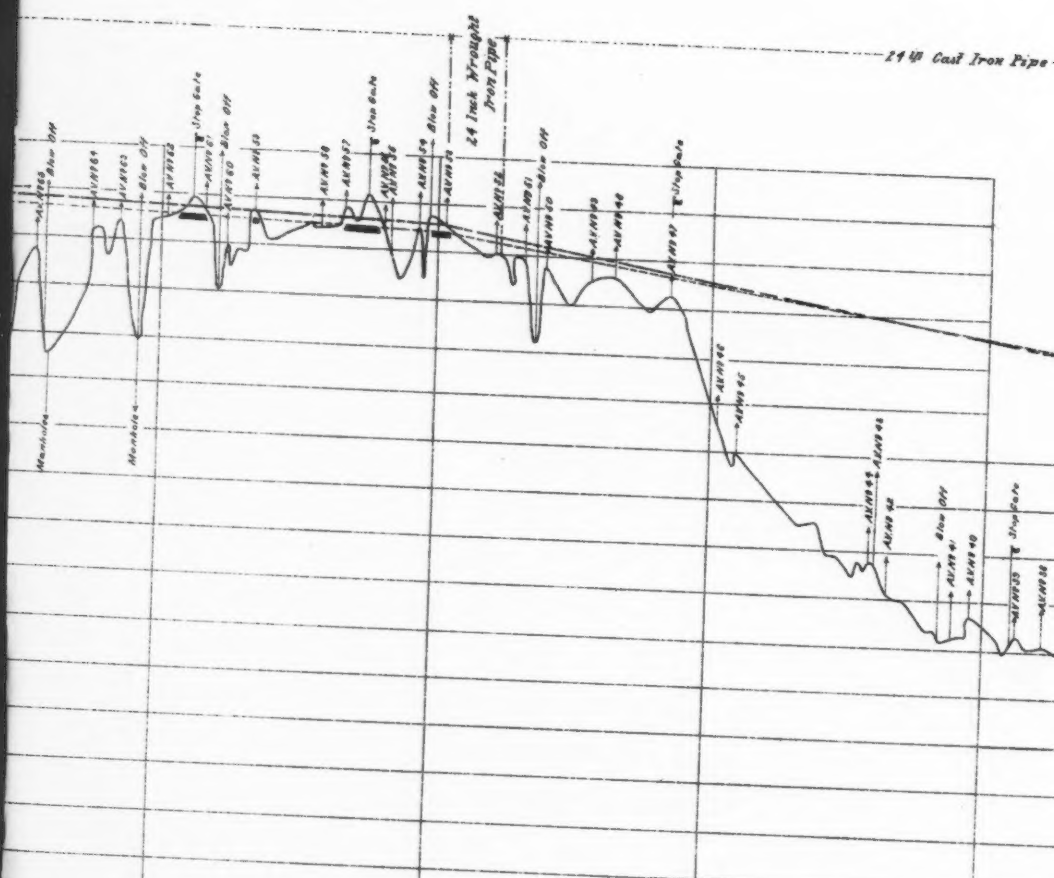
NOTE.—The discussion on this paper and the next follows the latter.


HEMLOCK LAKE
36 Inch Wroug
Canadice Outlet
Stop Gate
Blow Off
A.V. No 91
A.V. No 90
A.V. No 89
A.V. No 88
A.V. No 87
A.V. No 86
A.V. No 85
A.V. No 84
A.V. No 83
Blow Off
A.V. No 82
A.V. No 81
A.V. No 80
A.V. No 79
A.V. No 78
A.V. No 77
Blow Off
A.V. No 76
A.V. No 75
Stop Gate
A.V. No 74
Manhole
Manhole
Manhole
Manhole
Manhole
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
00
0
100
200


36 Inch Wrought Iron Pipe
24 Inch Wrought Iron Pipe
Stop Gate
Blow Off
Manhole
300
400
500

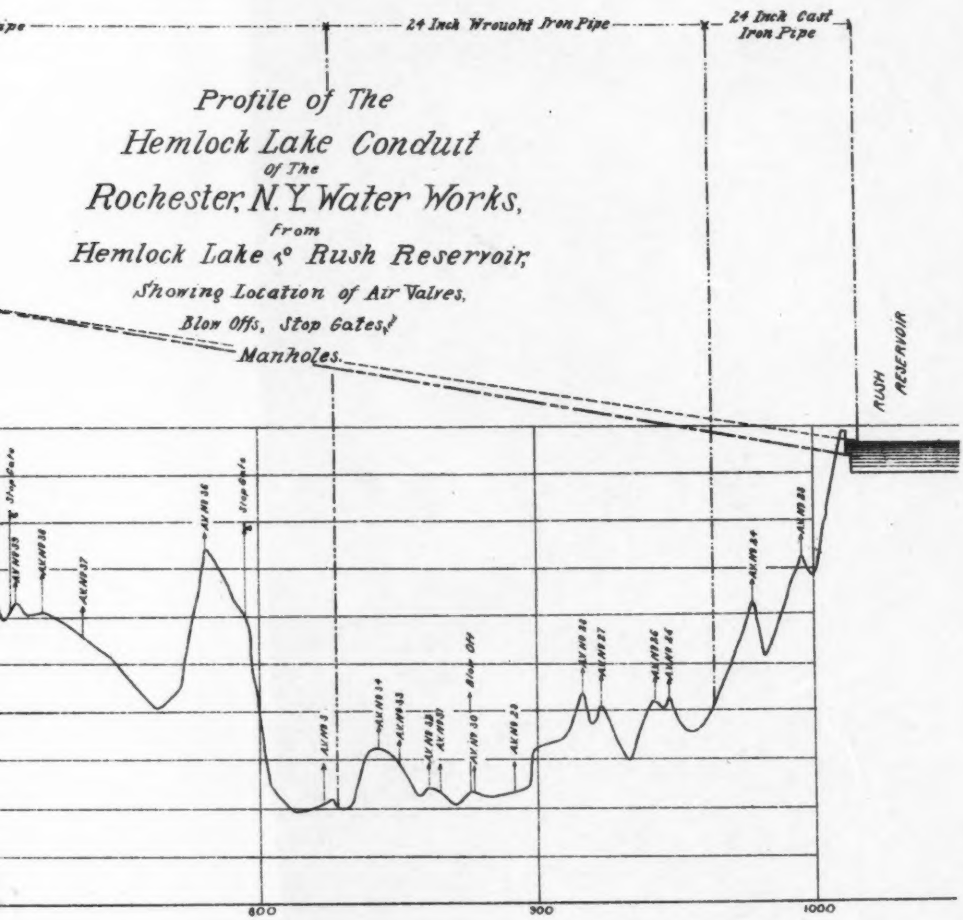


24 in Cast Iron Pipe
Profile of The
Hemlock Lake Conduit
Of The
Rochester, N.Y. Water Work
From
Hemlock Lake to Rush Reserv
Showing Location of Air Valves,
Blow Offs, Stop Gates, &
Manholes.
Blow Off
Stop Gate
600
700
800



24 Inch Wrought Iron Pipe
24 in Cast Iron Pipe
Manhole
Blow Off
Stop Gate
400
500
600
700

PLATE XII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No 520
RAFTER. HYDRAULICS OF
HEMLOCK LAKE CONDUIT.



AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

521.

(Vol. XXVI.—January, 1892.)

ON THE MEASURES FOR RESTRICTING THE USE AND WASTE OF WATER, IN FORCE IN THE CITY OF ROCHESTER, N. Y.

By GEORGE W. RAFTER, M. Am. Soc. C. E.

WITH DISCUSSION.

In a paper "On the Hydraulics of the Hemlock Lake Conduit of the Rochester, N. Y., Water-Works," the author has indicated that the present population of Rochester, as per census of 1890, is 133 896, and that the daily delivery of water from Hemlock Lake is now only a little over 6 700 000 gallons, instead of 9 292 800, as originally published. Ever since 1888 the question of constructing additional works has been actively discussed by the municipal authorities; but a feeling of distrust on the part of many citizens as to the immediate necessity for additional works has thus far engendered an opposition sufficiently strong to prevent, until recently, the project assuming tangible form; and it has therefore become necessary to make the most economical use of the present limited supply. The measures adopted last year for curtailing waste and preventing unnecessary use will be briefly described.

Referring to the accompanying skeleton map of the pipe distribution system (Plate XIV), it will be seen from the elevations there given that the city is chiefly situated in a nearly level plain, what little slope there is being from the south towards the north. The total area is something like 16 square miles, and the proportion of this covered by the distribution system is also shown on the said map. All of this area, except about 1.5 square miles in the business portion, which is protected by the Holly system, depends upon the Hemlock Lake supply not only for water for domestic and manufacturing use, but for fire protection by direct pressure from the hydrants as well; and any measures for restricting use and decreasing waste must, perforce of necessity, be designed with reference to fire protection as a controlling factor.

In July and August, 1888, both of the reservoirs were so nearly depleted as to leave only one or two days' storage on hand, and the situation was nearly as alarming in the summer of 1889. Fortunately no accident occurred either year to interrupt the flow through the single conduit from Hemlock Lake, and the city has thus far been delivered from the discomfort of a water famine. In the spring of 1890, the probability of a recurrence of the deficiency of the two previous hot seasons led to a large amount of discussion as to methods of restriction, and some of the municipal authorities took ground to the effect that the conditions were such as to render it impossible to avoid a water famine during the hot weather of that year. As is usual in such cases many suggestions were made, but none were sufficiently comprehensive to meet the condition of compelling a decrease in the use and waste of water, sufficient to bring the daily consumption within the limit of the daily supply and at the same time furnish fire protection. Some of these suggestions were interesting by reason of the lack of appreciation of the conditions which they presented, and one of them may be noticed as an example of this kind. The proposition in question was to control the delivery to the city by partially closing the outlet gates at Mount Hope Reservoir, thereby allowing the large supply mains leading down the hill to run partly full. Inspection of the map will show that the general level of the city is something over 100 feet below Mount Hope, and is reached in a horizontal distance of, say, half a mile, and the effect of adopting this suggestion will be understood after a brief description of the fire system in use. The reservoir is connected with the fire-alarm telegraph, and on receiving an alarm the gate-keepers, who are constantly on duty, by change of

ADDITIONAL REFERENCE.

1.—Elevations in feet above City datum are shown by figures in loop, thus: (250.0)

2.—Location and number of Fire Alarm Boxes are shown by figures in circle, thus: (24)

3.—Locations of Fire Department Stations are shown by black squares, thus: ■

4.—Locations at Pressure Reducing Stations are shown, thus: ◉

5.—Lines of Distribution Pipe 10 inches in diameter and upwards are indicated by figures on the several lines, thus: (12)

MAP SHOWI

Lines of Water Pipe, Fire Hydrants, Sto

IN THE STREETS OF THE CITY OF ROC

DOMESTIC SYSTEM

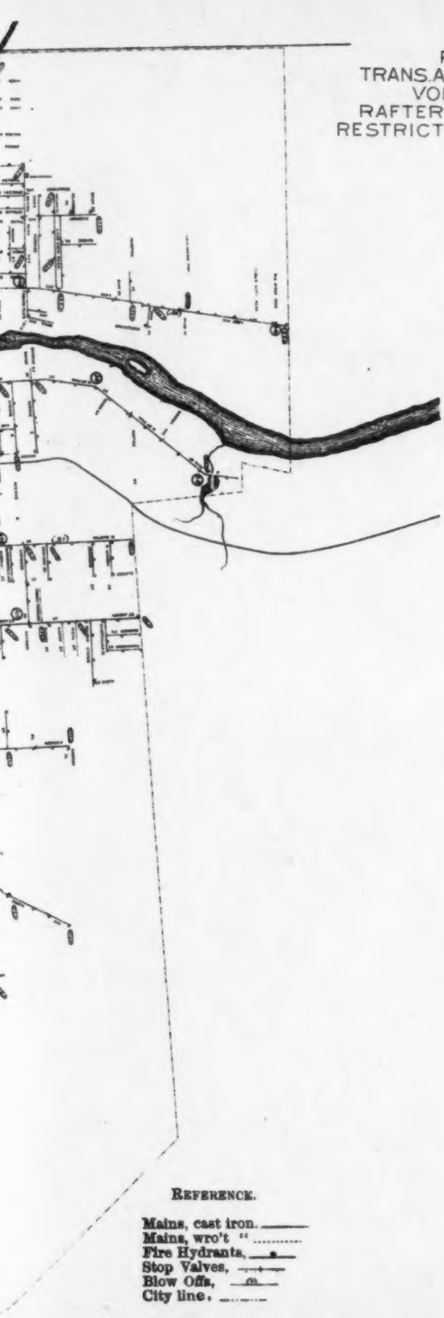
MAP SHOWING

Lines of Water Pipe, Fire Hydrants, Stop Valves and Blow Offs,

IN THE STREETS OF THE CITY OF ROCHESTER, N.Y.

DOMESTIC SYSTEM.

PLATE XIV.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XXVI. No 521.
RAFTER. MEASURES FOR
RESTRICTING WASTE OF WATER.



REFERENCE.

Mains, cast iron.
Mains, wro't "
Fire Hydrants,
Stop Valves,
Blow Offs,
City line.

w Offs.

gates at Mount Hope, immediately put the city distribution under the additional pressure due to Rush Reservoir. For this purpose Mount Hope is cut out for the time being and the distribution system fed direct from Rush instead. The plan for restriction that the author is now discussing also proposed to decrease the use and waste by so reducing the supply at night as to allow the supply mains to run nearly empty, thereby allowing the distribution system to become partly empty.

In order to test the rationality of this view a computation of the total contents of the distribution system was made, and it was found to be in the vicinity of 2 200 000 gallons, and by way of further testing the matter it was then assumed that a fire alarm might come in when the distribution system lacked 500 000 gallons of being full. Two 16-inch mains lead from Mount Hope to the city, and 5 000 gallons per minute through each of these was considered to be the safe limit, or 10 000 gallons per minute through both. Under the assumed conditions it would require fifty minutes to fill the distribution system and restore fire pressure, during which time the average fire would, of course, burn itself out. Even if we assume the distribution system as only lacking 200 000 gallons of being full, and the rate at which water might be fed to the city as somewhat greater than indicated in the foregoing, this method of reduction is still shown to be impracticable at Rochester, where the integrity of the fire protection imperatively demands an immediate response to every alarm. Probably the original hint for this plan was obtained from practice in the lower part of the City of New York, where substantially the thing proposed for Rochester was in successful use for three or four years previous to the introduction of an additional supply by the new Croton Aqueduct. The conditions in New York are not the same as in Rochester. No dependence at all is placed upon direct gravity pressure from the street mains for the suppression of fires. Steamers are used in every case, and presumably in sufficient number to control the worst fires, the street mains furnishing merely a handy reservoir system from which the steamers take suction. In Rochester, on the contrary, steamers are scarcely used at all. Only four are in commission for the whole city, and but two of these go to an ordinary fire. For several years after the completion of the Hemlock Lake supply their use was entirely discontinued, and the author is under the impression that a number owned by the city were sold to other towns. The increased use of water, however, has naturally decreased the effective pressure, and their use has again been

resorted to as an auxiliary to direct gravity pressure from the Hemlock Lake system, outside the Holly district.

As warm weather came on in the summer of 1890 the use of water in the city gradually increased until the daily use was from 1 000 000 to 2 000 000 gallons in excess of the supply, and the storage was accordingly depleted from day to day by that amount. The alarm occasioned by this state of affairs at the beginning of summer has been referred to in the accompanying paper. Some of the municipal authorities still persisted in the view that there was absolutely no way of averting a water famine, but finally the Executive Board directed the author to devise methods of restricting the use and waste, as also referred to in the preceding paper. A study of the conditions indicated that a reduction of pressure might be made by partially closing gates on the main feeding lines in the general level of the city, without involving the objectionable features of the plan just discussed. Pressure-reducing stations were accordingly located at the points shown on the map—those at the junctions of (1) South avenue and Caroline street, and (2) Flint and Mansion streets being both on the main 16-inch feeders to the east side and to the west side respectively. By closing a few gates on small cross mains the whole supply was passed through the gates at these two points. The stations were furnished with fire gongs and telephones, each connected with its own proper system. A pressure gauge attached to the main at that side of the gate on which the pressure was to be reduced, completed the outfit of the stations. A few pressure gauges were also located in private houses at critical points in the city. The station at the junction of Mount Hope avenue and Linden street was installed as a precautionary measure purely, the only duty of the attendant there being to open gates on the cross lines in case of an alarm of fire from certain boxes in that vicinity. The station at the junction of Strong and Seward streets on the 16-inch feeding main was for a different purpose. By trial it was found that a very moderate reduction of pressure at Flint and Mansion streets left relatively high ground in the vicinity of Magnolia and Mansion streets without water, which was remedied by the location of the secondary station on the 16-inch main at Strong and Seward streets. The closing of the gate at this secondary station deflected the flow of water from the main feeder, through the small cross mains leading to the high ground, and at the same time assisted in keeping the total flow within the desired limit.

By such a system it became very easy for a person located at a central point and provided with a telephone in connection with the pressure-reducing stations, to so manage the pressure in the different parts of the city as to just give a flow in the second stories of houses at the higher points. This meant a general lowering of pressure of from 10 to 20 pounds, and the immediate effect of this and the other restrictive measures inaugurated was to reduce the use and waste of water something like 1 800 000 gallons a day. The draft on the storage ceased at once, and in sixty days both reservoirs were full, and there is no good reason why, with economical management, they cannot be kept full, and aside from street and lawn sprinkling the necessary legitimate uses of water be supplied for two or three years, during which time the additional supply construction may be completed.

In the way of additional restrictive measures other than reduction of pressure in the manner indicated, a systematic house-to-house inspection was inaugurated, and all horse troughs throughout the city were fitted with automatic attachments; by this latter expedient a saving of something like 160 000 gallons a day was produced. The summer season of 1890 was one of frequent rain-fall, and the absence of water for lawn sprinkling was not felt. A large portion of the street sprinkling in Rochester is done with water from the Holly system, and for the last year the legitimate use of water from the Hemlock system for sprinkling, had it been allowed, would not have exceeded 800 000 gallons a day. The effect of the pressure reduction system was, therefore, a net saving of at least 800 000 gallons a day. How this saving was effected may be understood by considering that there are about 25 000 services in the city, of which 2 850 are metered. The leakage is an unknown quantity, but in a distribution system comprising over 200 miles of pipe, it may be safely taken as an appreciable one; and by way of illustrating the matter the author ventures to cite the fact that a sixty-fourth of an inch opening under 100 feet head will discharge something like 50 gallons in twenty-four hours, while the same opening under 50 feet head discharges only about 35 gallons in twenty-four hours. With services under a heavy pressure the tendency is to consume for purely domestic and toilet uses more water than is really necessary, and especially is this true when self-closing attachments are not used. This tendency is, of course, corrected by decreased pressure.

During the period of about sixty days from the middle of July to

the middle of September, 1890, the use of water from the Hemlock Lake system was an average of say 6 000 000 gallons a day, amounting for a population of 133 896—the greater proportion of which are fully served—to 44.8 gallons per day each. During the months of July, August and September of the same year, the use from the Holly system averaged 2 000 000 gallons a day, or 15.0 gallons per head of the population, making the total use of water in the city during these hot months an average of 59.8 gallons per head per day. In this connection, it is but fair to again state that the use of water for street and lawn sprinkling by hose was prohibited during the period in question.

It is unnecessary, in a paper before this Society, to amplify as to the importance of a definite knowledge of the flow of a supply conduit, such as may be obtained from frequent and approximately exact gaugings. A failure to obtain this information has led (1) to cumbering the annual reports with questionable statistics; (2) to a long-continued controversy as to the necessity of an immediate additional supply, in which the misleading of the public as to the real facts of the case may be considered an injury to the municipality—a controversy which, however, terminated as soon as the significance of the gaugings became fully understood; (3) to a general movement in favor of metering, which, if carried out under existing conditions, would have aggravated a situation already sufficiently unsatisfactory.

The author would state that the work detailed in this and the former paper has resulted in a marked improvement in a number of directions of considerable financial value.

DISCUSSION.

E. Kuichling, M. Am. Soc. C. E.—In reviewing Mr. Rafter's papers, one cannot fail to notice the brevity of the description of the data upon which highly important conclusions are founded, and inasmuch as these conclusions are at variance with the results of experience elsewhere, it becomes allowable to question the premises upon which the said conclusions were reached, in the hope that more light will be cast upon details that have been omitted in this paper.

During the past year the original field notes of the piezometer and pressure gauge observations on the conduit mentioned, as recorded by Mr. Rafter's assistants, have been in my custody, and a careful study of them does not warrant me in accepting Mr. Rafter's demonstration of his propositions as unqualifiedly correct or satisfactory for the following reasons:

First.—The observations given by Mr. Rafter in Table No. 1 do not appear to have been simultaneous, or even taken on the same day. From the well-house to air valve 70, they refer to July 30th and 31st; from air valve 69 to 67 inclusive, to August 2d; at air valve 66, to August 4th; from air valve 64 to 63, to August 1st; at air valve 61 and 60, to August 4th; from air valve 59 to 57, inclusive, to August 1st; at air valve 56, to the average between readings taken on July 31st and August 5th; from air valve 55 to 47, inclusive, to August 4th; from air valve 46 to 37, inclusive, to August 5th; the first of the two bracketed observations at air valve 36 refers to August 5th, while the second refers to August 16th; and all the remaining observations refer to August 16th. At air valves 40 and 41, moreover, only one or two widely different readings of the pressure gauges at each place on the same day are given. It is also omitted to mention that during the period from July 30th to August 16th, the water surface in the reservoir at the end of the conduit rose 3.48 feet, while in the well at the beginning of the conduit there was a fall of 0.15 feet during the same time. All of the available data relating to these observations have been compiled in the appended Table A.

Second.—It is not stated that appreciable fluctuations occurred in the level of the water in the piezometers, or open stand-pipes, attached to air valves 91 to 47, inclusive, nor that during the days on which the observations were made, a number of leaky joints on the 36-inch pipe were being repaired, thereby altering the hydraulic conditions somewhat, even though the leakage may have been relatively small. To indicate the magnitude of these fluctuations, I would mention that repeated observations at air valve 53 have been made by me during the past twelve months at times when the entire conduit was reported to be free from appreciable leakage and no repairs whatever were being made thereon, with the result of finding irregular periodic differences of from 0.05 to 0.07 feet, when the conduit was practically free from air at the numerous summits; whereas, when the observations were made without having previously opened the air valves along the whole line, the fluctuations were found to be somewhat greater, not only at air valve 53, but also at a number of other places where the normal hydraulic grade does not rise above the top of the stand-pipe attached to the valve. On the other hand, among the data left by Mr. Rafter's assistants in the office, there are records of relatively great and sudden fluctuations on the same days at air valves 55, 56 and 57, of which no explanation is given. From

my own experience, I am inclined to attribute these sudden changes of level in the stand-pipes to the movement or escape of masses of air which had been allowed to accumulate at the summits, or to gain admission into the conduit through those air valves on the 36-inch pipe which also serve as vacuum valves, when the discharge of said pipe is temporarily increased by opening one of the numerous blow-off valves for any purpose. This view is confirmed by the statements of the keeper of the reservoir, that during the summer of 1890, and for some time previously, he frequently saw large bubbles of air escape from the end of the submerged inlet pipe or conduit, and that such discharge was often accompanied by a loud rumbling sound. It therefore follows that without proof of the permanence of the hydraulic conditions of the conduit during the period from July 30th to August 16th, 1890, the conclusions stated by Mr. Rafter cannot be accepted as scientifically demonstrated facts.

Third.—In referring to the observations with pressure gauges, made for ascertaining the elevation of the hydraulic gradient at points on the 24-inch conduit where the application of piezometers is impracticable, it is not stated whether the same gauges were used throughout, nor how such gauges were rated or standardized. Every one who has had occasion to make use of such instruments has doubtless experienced some difficulty in ascertaining their accuracy, especially when small differences are to be measured at various pressures, as in this case. From the field notes it may be inferred that up to August 6th, a pair of the Utica Steam Gauge Company's diaphragm gauges, Nos. 77 349 and 77 805, were used, and that for the observations taken on August 15th and 16th a pair of Schäffer & Budenberg gauges, Nos. 1 076 544 and 1 076 545, were employed. In a remark in said field notes, under date of August 5th, 1890, it is mentioned that one of these gauges, probably No. 77 805, was "bad," and that "No. 77 805 gives 1 pound too much," although no standard of comparison is indicated, except the other gauge of the pair. The only record of any test of the gauges refers to Nos. 1 076 544 and 1 076 545, and occurs at the end of the observations in the field book of one of Mr. Rafter's assistants, but as this record bears no date, it is uncertain whether the test was made before or after the field work. On inquiry from an employee who remembered the circumstance, it was learned that said two gauges were tested by means of a force pump in comparison with a "test gauge" made by the Utica Steam Gauge Company, and owned by the Woodbury Engine Company of this city; also that such tests were made before the gauges were applied to the air valves, and that no test was made after they had been so used. Furthermore, it is stated by Mr. W. J. Creelman, the mechanical engineer of said engine company, that while the "test gauge" mentioned had originally been carefully standardized by its makers, yet it had not been compared with an accurate standard for a long time prior to July, 1890, and hence that its accuracy

at the time of the conduit observations was unknown. Following is the record of the test of said gauges as taken from the field-book:

Woodbury (Engine Company's Test Gauge).	(Schäffer & Budenberg) No. 1 076 545.	(Schäffer & Budenberg) No. 1 076 544.
31.	30	30.5
47.	45	45.5
62.	60	60.5
76.	75	75.25
90.	90	90.
104.	105	105.
119.	120	120.
37.5	35	35.5
52.	50	50.
66.	65	65.25
84.	80	80.
94.75	95	95.
109.	110	110.
118.	120	120.
52.25	50	50.
32.5	30	30.5

It will be observed that while the two Schäffer & Budenberg gauges show only slight differences, yet they vary materially from the "test gauge" with which they were compared; and in view of these relatively large differences, it is obvious that some measures should have been taken to ascertain the true ratings of the two gauges used in the field before deciding that the friction in the 24-inch wrought iron pipe is so much greater than in the cast iron pipe, since possible errors of from 2 to 4 pounds per square inch will make a very marked difference in the deduced position of the hydraulic gradient.

In connection with this subject of the accuracy of spring or diaphragm gauges, it may be of interest to mention that the Schäffer & Budenberg gauge No. 1 076 544 was tested a few months ago with a measured head of 10 feet of water, and the pointer barely moved from the zero pin, the indication being about one-half pound per square inch pressure for this head. The writer has also caused several of the Utica Steam Gauge Company's instruments to be tested recently under accurately measured heads of water, ranging from 5 feet to 205 feet, and has found errors in the dial graduations of nearly 2½ pounds, sometimes too much and sometimes too little. Temperature is likewise a factor in determining the pressure with such a gauge. In operating with an aneroid barometer, great differences are noticed between the readings of the instrument in the shade and in the sun at precisely the same spot, and when a check instrument fails to show any difference whatever in the atmospheric pressure; and since a diaphragm pressure gauge is constructed on the same principle as the aneroid, it follows that it may also be subject to variations of indication of the same pressure under

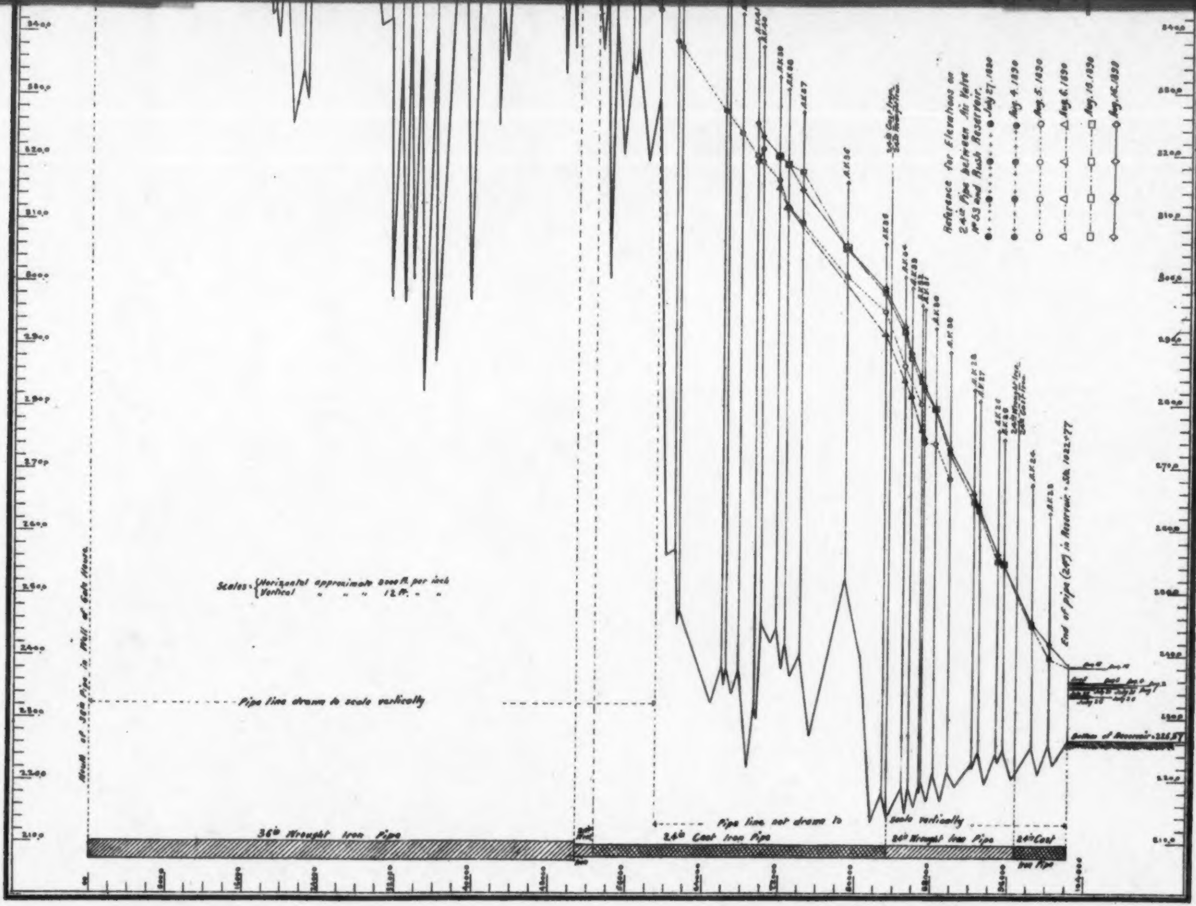
different temperatures. To obtain the proof of this assertion, the following experiment was made by the writer a few days ago.

Gauge No. 77 348 of the Utica Steam Gauge Company was attached to a short iron pipe bent twice at right angles, with two vertical and one horizontal sections. The other end of said pipe was connected with a long rubber hose suspended from a high window by means of a rope and a steel tape, and water was introduced below at the junction of the hose and the iron pipe by means of a force pump, in order to drive out any entrained air. A series of readings at different measured heads were taken with the apparatus at the prevailing temperature of the air (62 degrees Fahr.) and the water (52 degrees Fahr.), whereupon the water in the short horizontal section of the iron pipe was heated by means of an alcohol lamp to a temperature of 104 degrees Fahr. without imparting an appreciable quantity of heat to the mass of cold water in the rubber hose. After this temperature had been maintained for about one-half hour, in order that the air which had been compressed in the gauge might also become warmed, as well as the diaphragm box, another set of readings at exactly the same heads as before was taken. The results thus obtained were as follows:

Measure Head of Cold Water above Center of Gauge, in Feet.	Corresponding Correct Pressure in pounds per square inch.	Pressure indicated by Gauge when cold.	Pressure indicated by Gauge when heated to 104 degrees Fahr.	Temperature of Water in the Hose.	Temperature of Air in Shade.
46.6	20.14	19.75	19.25	52 deg. Fahr.	62 deg. Fahr.
31.6	13.69	13.00	14.00	"	"
16.6	7.19	7.50	7.00	"	"

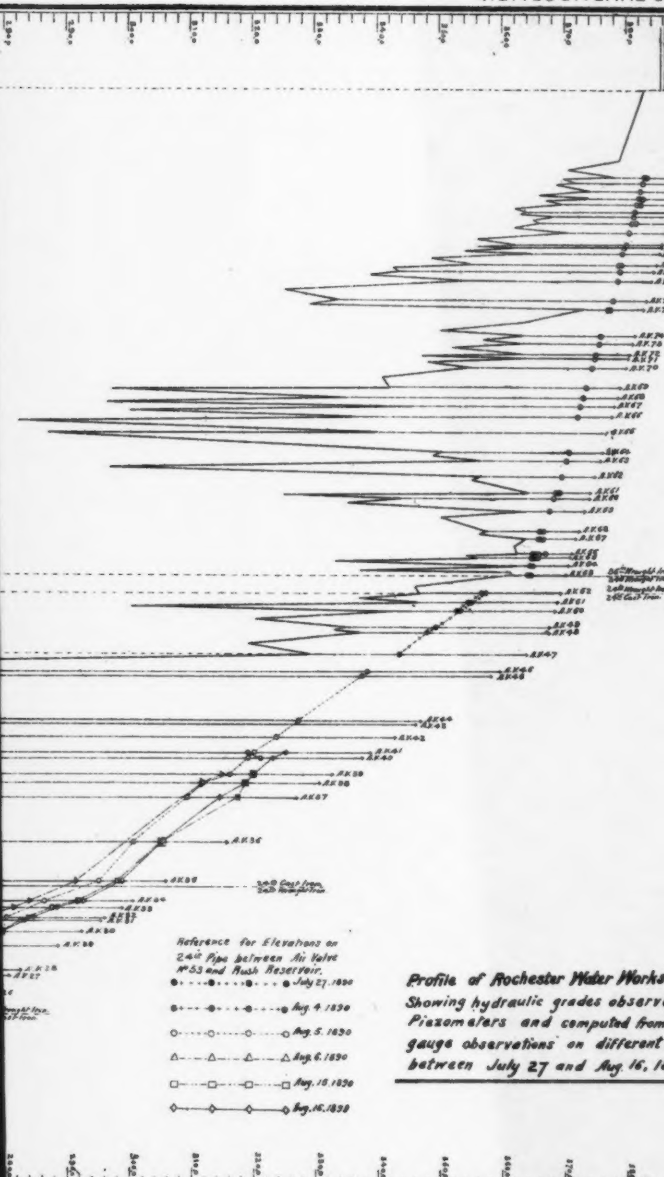
The foregoing table clearly shows the effect of changing the temperature of the gauge, or the compressed air within the diaphragm-box thereof, and hence also proves the proposition that metallic gauges are not reliable as a means of determining small differences of pressure, unless carefully rated and adjusted for variations of temperature.

Fourth.—In Mr. Rafter's paper, it has been assumed that the nominal diameters of the conduit are also the actual diameters. This assumption is hardly justifiable when dealing with the losses of head in different portions of the line. To ascertain the facts in the case, the writer has recently caused a number of the pipes which were left over after the completion of the works to be carefully callipered, with the following results: The heaviest class of the 24-inch cast iron pipe was found to be 23.97 inches in diameter, while the lightest class was 24.84 inches in diameter; of the two intermediate classes, no pieces were found which could be identified. In the 24-inch wrought iron pipe, the mean diameter of the accessible sections forming "inside" courses or sheets



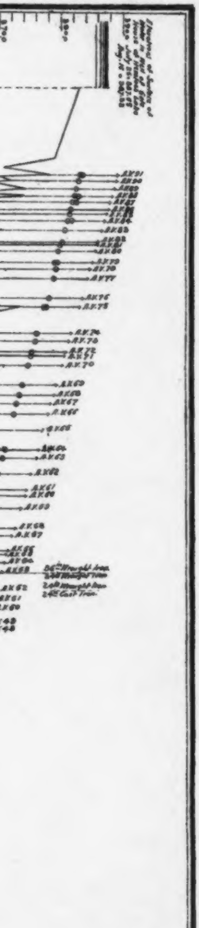
Mouth of 36in Pipe in Wall of Gate House
Scales: Horizontal approximate 2000 ft. per inch
Vertical " " 12 ft. " "
Pipe line drawn to scale vertically
Pipe line not drawn to scale vertically
36in Wrought Iron Pipe
24in Cast Iron Pipe
24in Wrought Iron Pipe
24in Cast Iron Pipe
End of pipe (24in) in Reservoir - Sta. 1022+77
Bottom of Reservoir
Reference for Elevations on 24in Pipe between Air Valve No. 53 and Rush Reservoir.
July 27, 1890
Aug. 4, 1890
Aug. 5, 1890
Aug. 6, 1890
Aug. 10, 1890
Aug. 16, 1890

PLATE XII
TRANS. AM. SOC. CIV.
VOL. XXVI. Nº 5
RAFTER, HYDRAU
HEMLOCK LAKE C



Profile of Rochester Water Works
Showing hydraulic grades observe
Piezometers and computed from
gauge observations on different
between July 27 and Aug. 16, 18

PLATE XIII.
...M.SOC.CIV.ENGRS.
...LXXVI. Nº 520
HYDRAULICS OF
...CK LAKE CONDUIT.



... Water Works Conduit,
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... computed from pressure
... on different dates,
...and Aug. 16, 1890.

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was found to be 24.09 inches. It is, however, hardly probable that any close uniformity of diameter was maintained in the manufacture of either the cast or the wrought iron pipes, since inequalities in the formation and shrinkage of the cores of the former, and appreciable variations in length of sheet or plate in the latter, are both practically unavoidable.

Another omission in the paper is in reference to the means used in changing the direction of the pipe, both in grade and alignment, during the construction. As a matter of fact, the records left in the office indicate that in the 36-inch pipe there are at least sixty abrupt angles or elbows with deflections ranging from 5 degrees to 40 degrees, and that in the case of the 24-inch wrought iron pipe a large number of abrupt angles ranging from 8 degrees to 20 degrees were made. For the cast iron pipe, on the other hand, a variety of cast iron curves of long radius were provided at all places where the deflection was too great to be made in the hubs or bells. In the wrought iron pipe, some of these angles were made with suitable cast iron bevel or angle hubs, while the larger ones were made by cutting one or more sheets to the required angle. It is also a fact that the cast iron pipe was used where the route was smoothest, as will be seen by reference to the profile exhibited, and hence in estimating the friction loss in the wrought iron sections, due allowance for loss of head from abrupt changes of direction should be made. The question accordingly arises how great such losses of head actually are in the case under consideration, and to this the writer is at present unable to give any answer, since he is unacquainted with any experiments of this kind with pipes of the magnitude here presented. It may also be remarked that a small allowance for head due to velocity should be made in considering the hydraulic grade between air valves 52 and 53.

To further illustrate the uncertainty of the data derived from the pressure gauge records, attention is invited both to the accompanying Table A, and to the profile or diagram, Plate XIII, giving a graphical representation of this table. A striking example is afforded by the records of the observations at air valves 40 and 41 on August 5th, where, in a length of 655 feet of cast iron pipe, an ascending hydraulic grade of 2.18 per thousand is found in the forenoon, while in the afternoon of the same day the grade is found to be descending at the rate of 0.98 per thousand; but on August 16th, the same grade is found to be descending at the rate of 2.15 per thousand. Another example is given by the records at air valves 30 and 31, which are on the 24-inch wrought iron pipe and 1 143 feet apart. Here on August 5th, a grade of 0.11 per thousand is deduced, while on the 15th the computation makes the grade 2.94, and on the 16th it becomes 3.52 per thousand. Still another case is presented at air valves 25 and 26, which are 599 feet apart on the 24-inch wrought iron pipe, and where on August 15th, we find a hydraulic grade of 0.29

TABLE A.—SHOWING ELEVATIONS OF HYDRAULIC GRADE AT VARIOUS POINTS ON CONDUIT AS DEDUCED FROM OPEN STAND-PIPES AND PRESSURE GAUGES.

Number of Air Valve.	Diameter of Pipe.	Continuous distance from Gatehouse Well.	Dates 1890.											
			July 25.	July 26.	July 27.	July 30.	July 31.	Aug. 1.	Aug. 2.	Aug. 4.	Aug. 5.	Aug. 6.	Aug. 15.	Aug. 16.
			Elevation of Water in Well of Gatehouse at Hemlock Lake.											
	36 inches.	0.0	387.65	387.65	387.65	387.48	387.49	387.49	387.48	387.45	387.44	387.60	387.35	387.33.
			Elevation of Water in Open Stand-pipe at Air Valves.											
91	36 "	9 198	383.01	....	....	383.49	....	....	....	....	....	....	....	....
90	36 "	9 821	382.76	....	....	....	....	....	....	....	....	....	....	....
89	36 "	10 612	382.43	....	....	....	....	....	....	....	....	....	....	....
88	36 "	11 430	382.14	....	....	....	382.75	....	....	....	....	....	....	....
87	36 "	12 006	381.82	....	....	....	382.43	....	....	....	....	....	....	....
86	36 "	12 820	381.55	381.49	....	....	....	....	....	....	....	....	....	....
85	36 "	13 298	....	381.38 (a)	....	....	....	....	....	....	....	....	....	....
84	36 "	13 983	381.71	381.11 (b)	....	....	....	....	....	....	....	....	....	....
83	36 "	15 008	380.74	380.58 (c)	....	....	....	....	....	....	....	....	....	....
82	36 "	16 145	....	379.99	....	....	....	....	....	....	....	....	....	....
81	36 "	16 533	....	379.78	....	....	....	....	....	....	....	....	....	....
80	36 "	17 120	....	379.50	....	....	....	....	....	....	....	....	....	....
79	36 "	18 415	....	378.88	....	379.49	....	....	....	....	....	....	....	....
78	36 "	19 132	....	....	....	379.21	....	....	....	....	....	....	....	....
77	36 "	20 092	....	....	....	378.82	....	....	....	....	....	....	....	....
76	36 "	22 037	....	....	....	377.98	....	....	....	....	....	....	....	....
75	36 "	23 087	....	....	377.12	377.51	377.52	....	....	....	....	....	....	....
74	36 "	25 875	....	....	....	....	375.95	....	....	....	....	....	....	....
73	36 "	26 606	....	....	....	....	375.75	....	....	....	....	....	....	....
72	36 "	27 817	....	....	....	....	375.25	....	....	....	....	....	....	....
71	36 "	28 119	....	....	....	....	375.13	....	....	....	....	....	....	....
70	36 "	29 251	....	....	....	....	374.64	374.67*	....	....	....	....	....	....
69	36 "	31 317	....	....	....	....	....	....	373.71	....	....	....	....	....

68	36	"	32 345	....	....	....	....	....	....	373.18	....	....	....	....	....
67	36	"	33 252	....	....	....	....	....	....	372.65	....	....	....	....	....
66	36	"	34 368	....	....	....	....	....	....		372.29	....	....	....	....
65	36	"	35 978	....	....	....	....	....	....	....	....	....	....	....	....
64	36	"	38 038	....	....	....	....	....	370.88	....	....	....	....	....	....
63	36	"	39 108	....	....	....	....	....	370.39	....	....	....	....	....	....
62	36	"	40 626	....	....	....	....	....	369.65	....	....	....	....	....	....
61	36	"	42 210	....	....	368.59	....	....	369.33	....	369.00*d*	....	....	....	....
60	36	"	42 862	....	....	....	....	....	368.33	....	368.36	....	....	....	....
59	36	"	44 134	....	....	....	....	....	367.62	....	....	....	....	....	....
58	36	"	46 370	....	....	366.12	....	....	366.61	....	....	....	....	....	....
57	36	"	47 070	....	....	365.74	....	....	366.28	....	....	....	366.45	366.69*c*	366.71*c*
56	36	"	48 615	....	....	365.08	....	365.44	....	....	365.49*e*	365 62	365.70	366.03*c*	366.99*c*
55	36	"	48 909	364.59*f*	364.57 *g*	364.77	365.09 *h*	365.25	365.21*i*	365.31	365.33	365.37	365.58*j*	365.89*k*	365.89*l*
54	36	"	49 703	....	....	364.59	....	....	....	....	365.08	....	....	....	....
53	36	"	50 820	363.97	....	364.11	....	....	....	....	364.65	....	....	....	....
	24	"	50 828	Beginning of 24-inch wrought iron pipe.					....	....	....	....	....	....	....
52	24	"	52 720	....	....	356.79	....	....	....	....	357.37	....	....	....	....
	24	"	52 722	End of wrought iron and beginning of cast iron 24-inch pipe.							....	....	....	....	....
51	24	"	53 658	....	....	354.63	....	....	....	....	355.18	....	....	....	....
50	24	"	54 502	....	....	352.73	....	....	....	....	353.35	....	....	....	....
49	24	"	56 209	....	....	....	....	....	....	....	349.57	....	....	....	....

TABLE A—(*Continued*).

Number of Air Valve.	Diameter of Pipe.	Continuous distance from Gate-house Well.	Dates, 1890.											
			July 25.	July 26.	July 27.	July 30.	July 31.	Aug. 1.	Aug. 2.	Aug. 4.	Aug. 5.	Aug. 6.	Aug. 15.	Aug. 16.
			Elevation of Water in Open Stand-pipe at Air Valves.								Elevation of Hydraulic Grade computed from Pressure Gauge Readings.			
48	24 inches.	56 946	....	....	....	....	....	....	....	347.94	....	....	....	....
47	24 "	59 141	....	....	....	....	....	....	....	343.55	....	....	....	....
46	24 "	61 036	....	....	....	....	....	....	....	....	338.40	....	....	....
45	24 "	61 514	....	....	....	....	....	....	....	....	337.78	....	....	....
44	24 "	66 038	....	....	....	....	....	....	....	....	327.35	....	....	....
43	24 "	66 235	....	....	....	....	....	....	....	....	....	....	....	....
42	24 "	66 710	....	....	....	....	....	....	....	....	323.72	....	....	....
41	24 "	69 323	....	....	....	....	....	....	....	....	{318.87 320.03}	....	....	325.05
40	24 "	69 978	....	....	....	....	....	....	....	....	{321.05 319.05}	....	....	322.90
39	24 "	71 635	....	....	....	....	....	....	....	....	316.05	314.84	319.94	319.90
38	24 "	72 616	....	....	....	....	....	....	....	....	311.81	311.81	318.53	318.56
37	24 "	74 180	....	....	....	....	....	....	....	....	309.19	....	317.32	314.51
36	24 "	78 763	....	....	....	....	....	....	....	....	300.51	....	305.18	305.20
35	24 "	82 857	....	....	....	....	....	....	....	....	294.93	291.47	298.15*e*	298.47
	24 "	83 238	End of	cast iron	and begin	ning of w	rought ir	on 24-inc	h pipe.					
34	24 "	84 913	....	....	....	....	....	....	....	....	286.36	283.97	291.78	292.38
33	24 "	85 623	....	....	....	....	....	....	....	....	....	281.35	287.58	28[illegible].18
32	24 "	86 133	....	....	....	....	....	....	....	....	280.16	275.94	283.85	284.45
31	24 "	87 097	....	....	....	....	....	....	....	....	274.05	274.80	282.50	283.10
30	24 "	88 240	....	....	....	....	....	....	....	....	273.94	....	279.56	279.58
29	24 "	89 791	....	....	....	....	....	....	....	....	268.27	....	272.31	272.91
28	24 "	92 237	....	....	....	....	....	....	....	....	....	....	264.52	265.69
27	24 "	92 842	....	....	....	....	....	....	....	....	....	....	263.05	263.65
26	24 "	94 855	....	....	....	....	....	....	....	....	....	....	254.89	256.07
25	24 "	95 454	....	....	....	....	....	....	....	....	....	....	254.60	254.62
	24 "	96 796	End of	wrought	iron and	beginnin	g of cast	iron 24-in	ch pipe.					
24	24 "	98 404	....	....	....	....	....	....	....	....	....	....	244.71	245.31
23	24 "	100 267	....	....	....	....	....	....	....	....	....	....	239.46	241.79
			Elevation of Water Surface in Rush Reservoir.											
	24 inches.	102 277	233.25	233.47	233.78	234.64	234.85	235.03	235.34	235.54	235.62	235.76	237.99	238.12

a = average of 5 observations on date.
b = " 6 " "
c = " 4 " "
d = " 7 " "
e = " 2 " "
f = " 11 " "

g = average of 33 observations on date.
h = " 23 " "
i = " 19 " "
j = " 18 " "
k = " 13 " "

NOTE.—In computing the height of the equivalent water column from the pressure gauge readings, it was assumed that one pound pressure corresponds to a height of 2.308 feet, or that a cubic foot of water weighs 62.392 pounds.

All of the elevations in the above table are relative to assume low water in lake = + 388.00.

per thousand, with the particular remark that the "gauges were tried several times" on that day, while on the following day the computed grade is 1.45 per thousand. It will be noticed that in some of these instances the computed grade in the wrought iron pipe is much less than the average grade in the cast iron sections, thus proving either the reverse of Mr. Rafter's proposition, or else that local obstructions occur in the other sections of the wrought iron pipe. Unfortunately, however, a rigid cross-examination of some of the foremen and mechanics who were employed in the construction of the works, failed to elicit much definite information as to the location of any obstruction, except that at a certain place in the cast iron pipe, where it was alleged that at least 700 pounds of molten lead had been poured into the pipe through a defectively yarned sleeve joint. Pressure gauges appear to have been applied at distances of 162 feet on each side of this particular spot, but the results were apparently unsatisfactory, since the resulting hydraulic grade was found to be only 1.08 per thousand, or less than one-half of the average. It is believed that the foregoing illustrations will suffice to point out some of the uncertainties which are attendant upon the use of ordinary pressure gauges as instruments of precision.

It is also proper to remark in this connection that the writer has no intention of disputing the correctness of the various observations and data presented by Mr. Rafter, nor of underrating his work, but he simply desires the presentation of all the facts in the case before judgment is passed. As the matter now stands, it may be conceded on broad lines that the friction in smooth and new cast iron pipe is somewhat less than in similar riveted wrought iron pipe, owing to the obstruction caused by rivet heads and the frequent alterations of diameter in passing from the inside to the outside courses or sections; but it scarcely seems probable that the difference is as great as claimed by Mr. Rafter, if due allowance for resistances caused by abrupt changes in direction is made. On this latter point, therefore, more light is needed, and meanwhile it may be considered that the enormous differences in friction urged by Mr. Rafter have not been conclusively demonstrated.

Concerning the existence of any appreciable obstruction in the pipes at any point, it may be mentioned that no satisfactory evidence thereof has yet been manifested by any test thus far applied. At the point where the diameter of the conduit changes from 3 feet to 2 feet, which is about midway between the lake and Rush Reservoir, a long steel probe was inserted through a specially designed tap, and the interior of the pipe for a length of about 6 feet found to be absolutely free. A similar exploration with like result was also made at the tapering casting at Rush Reservoir where the conduit divides into two branches, one leading into the reservoir and the other communicating with the pipe running to Mt. Hope Reservoir. It was thought that at these two points any loose plank or timbers left in the pipe during construction might

possibly have become lodged, but the examinations have proved otherwise. All of the blow-offs at the principal depressions in the conduit lines were likewise opened with the expectation of removing any accumulations of sand or mud; the discharge was, however, practically clear water in every instance, and hence no evidence of obstruction from such a cause was gained.

Owing to the inexpediency of emptying the conduit, no knowledge of the condition of its inner surface is now available, except what was obtained from the two probings above mentioned, in which no evidence of tuberculation by rust, mineral incrustation, sediment or vegetable growth was found. The only clue thus far obtained consists in the discovery of an extensive growth of spongilla on the interior surface of the 24-inch cast iron effluent pipe from Rush Reservoir, on each side of the stop gate in the gatehouse. This gate has long been out of order, and it was repaired on September 19th, 1890, the mouth of the pipe in the screening well of the reservoir being temporarily closed for this purpose by a plank shutter, whereupon the dome of the gate could be unbolted and removed. An opportunity was thus afforded to examine the interior of the pipe for a short distance on each side of the opening, and it was found that the top and sides of the pipe as far as arm could reach, as well as the inside of the gate castings, were entirely covered with the growth mentioned. A significant circumstance was that the pitch coating of the iron pipe appeared to peel off along with the foreign matter and remained adhering to the roots of the latter. Considerable corrosion was also noticed in places on the inner surface of the gate castings, while the brass facings or seats were covered with a thin film of calcareous or silicious matter which was easily scraped off with chisels.

The occurrence of such growths in cast iron water mains is not unusual. In a paper on the subject which was read before the American Society of Civil Engineers on October 15th, 1884, by Mr. Desmond FitzGerald, Resident Engineer on the Boston Water Works, the author states that "he has seen large mains, under a pressure of 100 feet, where the entire surface, as far as examined, was filled with masses of sponge closely packed between and around the tubercles (or accretions of rust). He has also seen them in all stages of growth. Within a few days a break in a 48-inch main gave an opportunity to examine the sponge in company with Professor Hyatt, who recognized the young sponge as *Spongilla lacustris*, variety *Flexis pina*. Flushing will not remove this growth. Some form of scraper or wire brush is necessary." Similar experiences have also been recorded by engineers in other cities, and it hardly seems necessary to enlarge further upon the subject.

E. Sherman Gould, M. Am. Soc. C. E.—I regret very much not being able to be present at the reading of these interesting papers, and to take part in the oral discussion of the same. It would be very desirable to know what kind of wrought iron pipe was used, for the experiments

seem to show that the flow is much less free in the wrought iron than in the cast iron sections. The actual flow, as compared with that originally calculated, seems to be accounted for by the author in the summary at the end of the paper, at least in part, by the statement that unsatisfactory work was stated to have been done in some places where the worst results were obtained. What was the nature of this unsatisfactory work, and was the pipe line as a whole below the average standard of ordinarily good work? These questions are very important, because the tendency of hydraulic engineers seems to be to use formulas giving higher and higher rates of discharge, which, as it seems to me, in view of the many probable imperfections which are liable to exist in even well inspected work, is of very questionable wisdom.

Table No. 2 is exceedingly instructive. In that we see that some 51 000 feet of wrought iron 36-inch pipe is connected with 1 900 feet of wrought iron 24-inch pipe, and further down in the same line there are about 10 500 feet more of wrought iron 24-inch pipe. The hydraulic grade line, as determined by actual experiment with piezometric tubes and pressure gauges, gives 0.45 feet per thousand for the 36-inch pipe, 3.83 feet for the first section of 24-inch pipe and 3.58 for the second. These figures give us the means of checking their own correctness. For whatever quantity of water passed through the 36-inch pipe per second must have also passed through the 24-inch pipes in the same time. Now, the discharging capacities of pipes of different sizes are as the square roots of the fifth powers of the diameters. Therefore the discharging capacity of the 36-inch pipe is 2.76 times that of the 24-inch. Moreover, using Darcy's co-efficients for rough pipes, the ratio in favor of 36-inch pipe is $\frac{64}{62} = 1.032$. Therefore the total capacity of the 36-inch pipe is 2.85 times that of the smaller. As the same volume of water per second must pass through the two, the ratio of their respective losses of head must counterbalance the 2.85 factor of the large pipe. Now the discharging capacities of pipes are as the square root of their losses of head, consequently the loss of head of the 36-inch pipe being 0.45 per thousand, that of the 24-inch should be 3.755, in order that the ratio of their square roots may be $\frac{1}{2.85}$. But by actual measurement this loss of head was in one case 3.83, and in the other 3.58, the average of which is 3.70, which is a very close agreement with the result, 3.755, of calculation. We may therefore accept the measurements as being rather unusually accurate.

Another fact arrests our attention. The probable discharge of the system was predicted, from previous calculations, as 9 292 800 gallons per twenty-four hours, or 14.39 cubic feet per second. It is to be regretted that the formula used was not given. By actual recent measurement the present discharge was found to be 6 742 000 gallons per twenty-

four hours, or 10.43 cubic feet per second. That is, the former elaborate calculation is for some reason nearly 38 per cent. in excess of the present reality.

Now let us see how a very rough and ready formula would have fitted the facts. Granting a considerable, but highly probable, degree of roughness, leakage or other modifying imperfections, a long pipe, 1 foot in diameter, with a grade of 1 foot in 1 000, will discharge 1 cubic foot of water in one second of time. This fact enables us to write the two simple formulas:

$$D = \sqrt[5]{\frac{Q^2}{H}} \qquad (1)$$

$$Q = \sqrt{D^5 \times H} \qquad (2)$$

in which:

D = diameter in feet.

Q = cubic feet per second.

H = loss of head per thousand.

Now taking the case of the 36-inch pipe, in which $H = 0.45$, we have, using equation (2): $Q = 10.46$, that is, a discharge of 10.46 cubic feet per second. But the actual discharge, by direct measurement, was 10.43 cubic feet per second; therefore the formula gives a practically identical result. As applied to the 24-inch pipes, the results are not so close, for the 3.83 grade gives 11.07 cubic feet per second, and 3.58 gives 10.70 cubic feet per second. These discrepancies, however, are in the right direction, for if the above formula gives a right result for a pipe of a certain diameter, it will give too large a result for a similar pipe of smaller diameter, and too small a one for a pipe of larger diameter.

To me, one of the most important features of these experiments is that they emphasize the fact that, in view of the many retarding influences at work inside of an ordinary pipe line, particularly after the lapse of years, during which the consumption is increasing, it is unwise to put faith in hair-splitting formulas which raise false hopes as to the capacity of the pipes.

It appears to me that the measures taken by the author for restricting waste were wise and intelligent. The distributing pipes of a large city, particularly when the circuits are connected, constitute a complicated arterial system in which the pressures at different points cannot be even approximately foretold. If it is desired to obtain an even distribution of water in such cases, the use of gates and gauges as described in the second paper seems to be inevitable.

Rudolph Hering, M. Am. Soc. C. E.—Mr. Rafter's first paper closes as follows: "In the opinion of the author the Rochester conduit cannot be taken as proving correctness of the modern views as to the value of c to be used in the formula $v = c \sqrt{RS}$ when pipes of large diameter and long lengths are under consideration."

Shortly before concluding, Mr. Rafter assumes certain hydraulic elements as to gradients, etc., and compares the results obtained therefrom with the results of the gaugings, and draws certain conclusions, the fifth of which, as a summary, cannot be gainsaid. But he says further, "considerable doubt is thrown by the results of these tests upon the original determination of the daily flow of 9 292 800 gallons in twenty-four hours, and until a thorough history of the interior of the pipe is available, it must be considered an open question as to whether such flow has ever taken place."

It is my purpose to present a few calculations respecting this pipe line, based on other gaugings, to show that when the pipes were new, the discharge of 9 292 800 gallons must have been very nearly the true one, and that the information given by Mr. Rafter does not disprove the correctness of the modern views as to the value of *c*.

I shall use for the calculations the data given in Table No. 2, comprising the results of recent gaugings, and I shall assume that in the third and fourth sections the pipes are cast and wrought iron respectively, for their whole length. This assumption will cause an error in the final result, but a comparatively small one, that will not vitiate the general results, and simplify the calculations.

HYDRAULIC ELEMENTS, ROCHESTER CONDUIT.

Air valves.	Length in feet.	Diameter of pipe.	Slope per 1 000.	Mean velocity in feet per second.	Co-efficients. *c*	Co-efficients. *n*
Well house at lake to 53..........	50 819	36 inches, wrought.	0.45	1.47	80.4	.0168
53 to 52	1 901	24 " "	3.83	3.32	76.0	.0166
52 to 35	30 137	{ 14 feet 24 " " 30 123 " 24 " cast. }	1.95	3.32	106.4	.0125
35 to 24	15 547	{ 427 " 24 " " 13 809 " 24 " wrought 1 311 " 24 " cast. }	3.43	3.32	80.2	.0158
34 to 25	10 541	24 " wrought.	3.58	3.32	78.5	.06

In the above table these data are partly repeated and I have added three columns in which there are given respectively, the mean velocity of the pipe, the co-efficient *c* in the Chezy formula and the co-efficient *n* in Kutter's formula. The latter represents the resistance mainly due to the roughness of the wetted perimeter, such as they exist in the pipe at the present time. It will be noticed that the values for wrought iron pipe in the different sections are 0.0168, 0.0166, 0.0158 and 0.0161 respectively, and that the value for the cast iron pipe is 0.0125.

The difference in the values of *n* referring to the different sections of wrought iron pipe agree well among each other. From other gaugings

of cast and wrought iron pipes that have been in use for a number of years, this co-efficient of roughness (.0158 to .0168) indicates a considerable degree of tuberculation.

For instance, a main in Jersey City gauged by Mr. Bailey in 1867 (Fanning, "Treatise on Hydraulics"), measuring 29 715 feet in length and 20 inches in diameter, known to be heavily tuberculated, give a co-efficient of roughness of $n = .0166$. The Croton main gauged by Kirkwood in 1867 is 11.217 feet long and 3 feet in diameter, also known to be heavily tuberculated, gives a co-efficient of $n = .0168$.

The co-efficient of roughness in the cast iron section (.0125) indicates but a slight change from the co-efficient for new pipe. Gaugings of new cast iron pipe give values as follows: In Hamburg* a 20-inch pipe 3 514 feet long gives a co-efficient varying from .0112 to .0119, according to the velocity, which correspondingly varies from 0.70 to 2.50 feet per second.

At Hackensack, New Jersey,* a 20-inch pipe, 75 000 feet long, having a number of bends and angles, gives a co-efficient varying from 0.0110 to 0.0127, for velocities ranging from 2 to 3 feet per second.

At Philadelphia* a 30-inch pipe 20 200 feet long, with easy curves, gives a co-efficient varing from 0.0113 to 0.0128, as the velocities ranged inversely from 3.23 to 1.47 feet per second.

In the Sudbury* conduit a 4-foot pipe 1 747 feet long, with easy curves, gives a co-efficient varying from 0.0105 to 0.0109, for velocities varying from 2.6 to 6.2 feet per second.

The co-efficient of roughness for new pipe under the above conditions varies therefore from .0105 to .0128, while that found in the Rochester conduit is .0125. Mr. Rafter's fifth conclusion, that the excessive resistance is mostly confined to the wrought iron section, is therefore substantiated by the gaugings of other and similar conduits, and in a very satisfactory way, for pipes of large diameter and long lengths; also by means of the modern formula and views as to the value of c in the Chezy formula.

Let us now ascertain the results of these same views with reference to the probable discharge of the conduit when it was new. Darcy* gauged a new wrought iron pipe about 12 inches in diameter and 365 feet long with velocities of 1.3 and 3.9 feet per second, the co-efficient of roughness being respectively .0110 and .0098.

H. Smith, Jr.,* gauged similar pipes nearly 13 and 15 inches diameter and each about 700 feet long with velocities 4.4 and 4.6 feet per second, in which the co-efficient of roughness varied from .0109 to .0110. He likewise gives the results of a pipe 17 inches diameter and about 4 440 feet long, giving for a velocity of 20.1 feet per second a co-efficient of roughness equal to .0099. Finally he gives a pipe 25 inches diameter

*"Flow of Water," by Ganguillet and Kutter. Translated by Hering and Trautwine. John Wiley & Sons. 1891.

and about 1 200 feet long and for a velocity of 12.6 feet per second a co-efficient of roughness equal to .0106.

Under the conditions as reported to have existed in the Rochester conduit when built, it will therefore appear safe to assume for them a co-efficient $n = .011$ as a probable maximum for wrought iron sections. For the cast iron section we are likewise justified from the gaugings previously quoted in assuming the co-efficient $n = .012$, as representing the probable maximum when the pipe was new. With these co-efficients let us now ascertain the discharge in a pipe line such as the Rochester conduit is described to have been.

We have, beginning at the lake:

(1) A 36-inch wrought iron pipe 50 819 feet long with a co-efficient of roughness of $n = .011$.

(2) A 24-inch wrought iron pipe 1 901 feet long with a co-efficient of $n = .011$.

(3) A 24-inch pipe, mostly cast iron, 30 137 feet long, with a co-efficient of $n = .012$.

(4) A 24-inch pipe, mostly wrought iron, 15 547 feet long, with a co-efficient of $n = .011$.

Let us designate the heads at the end of each of these four sections, respectively, to be h_1, h_2, h_3 and h_4. Let us further designate the mean velocity in the 36-inch pipe as v_1, and that in the 24-inch as v_2. It will be evident that the discharge in the 36-inch pipe and that in any of the sections of the 24-inch pipe must be equal. As the area of the 36-inch pipe is 7.07 square feet, and that of the 24-inch pipe 3.14 square feet, the discharge will therefore be equal to 7.07 v_1, and likewise equal to 3.14 v_2.

Let c_1, c_2, c_3, c_4, respectivley, represent the co-efficient for each of the four sections in the formula $v = c\sqrt{RS}$, in which v = mean velocity in pipe; R = mean radius of pipe; S = hydraulic slope.

If we substitute for S the head h divided by the length l and for $\sqrt{R}$ and l the respective numerical values, we have the following five equations:

$$(1) \quad 7.07 v_1 = 3.14 v_2.$$

$$(2) \quad v_1 = c_1 \times .866 \sqrt{\frac{h_1}{50\,819}}.$$

$$(3) \quad v_2 = c_2 \times .707 \sqrt{\frac{h_2}{1\,901}}.$$

$$(4) \quad v_2 = c_3 \times .707 \sqrt{\frac{h_3}{30\,137}}.$$

$$(5) \quad v_2 = c_4 \times .707 \sqrt{\frac{h_4}{15\,547}}.$$

As the entire head from the lake to the reservoir is 143.8 feet, we can add a sixth equation:

$$(6) \quad h_1 + h_2 + h_3 + h_4 = 143.8 \text{ feet,}$$

from which six equations the two mean velocities and the four heads can be computed, provided we substitute the numerical values of c. According to the Ganguillet and Kutter formula, we can neglect the effect of the variation of slope upon the co-efficient for the case in hand. Assuming this slope to be 0.411 per thousand for the 36-inch pipe, and 2.26 per thousand for the 24-inch pipe, we obtain from the formula:

$$c_1 = 131.7 \qquad c_3 = 112.3$$
$$c_2 = 125.0 \qquad c_4 = c_2 = 125.0.$$

Substituting these values in the above equations, substituting further, from equation 1, the value of v_1 expressed in terms of v_2, and reducing respectively to the values of h, we get:

$$(7) \quad h_1 = 0.770\, v_1^2 \qquad (9) \quad h_3 = 4.781\, v_1^2$$
$$(8) \quad h_2 = 0.243\, v_1^2 \qquad (10) \quad h_4 = 1.991\, v_1^2$$

Substituting these values in equation 6, we find the mean velocity in the 24-inch pipe, $v_2 = 4.30$ feet. From equation 1 we then get the mean velocity in the 36-inch pipe, $v_1 = 1.91$ feet, and from equations 7 to 10 the various heads:

$$h_1 = 14.2 \qquad h_3 = 88.3$$
$$h_2 = 4.5 \qquad h_4 = 36.8.$$

The discharge of the mains is, therefore,

$$7.07\, v_1 = 13.50 \text{ cubic feet per second, or,}$$
$$8\,725\,200 \text{ gallons in twenty-four hours.}$$

This quantity is not quite as great as that given originally, but as the assumption above made for the co-efficient n was rather large, in order to be on the safe side, I consider from the above independent data and above reasoning, the original quantity most likely to have been correct. As the recent tests were made in old pipe, evidently much tuberculated in the wrought iron sections, I therefore see no justification in the assertion of Mr. Rafter that by them "considerable doubt is thrown" upon the original determination of flow. It is also evident, notwithstanding the sentiment expressed in the last sentence of his paper, that the modern views as to the value of c have in the Rochester case rather been substantiated than otherwise.

John Thomson, M. Am. Soc. C. E.—Regarding Mr. Rafter's prefatory paper on the "Hydraulics" of the Rochester conduit, its evident object is to compare the past and the present maximum discharging capacity of the Rochester conduit and also to submit certain inferences as to the physical condition of its internal surface. The late Mr. L. L.

Nichols, C. E., made the first gauging of the discharging capacity of the Rochester conduit, acting as an assistant engineer under J. Nelson Tubbs, M. Am. Soc. C. E., then the Chief Engineer of the line. I had the honor of Mr. Nichols' acquaintance, and firmly believe that he was thoroughly competent to accurately determine the discharging capacity of the line in the construction of which he himself had performed an important part.

But the details of Mr. Nichols' gaugings, as observed and recorded by himself, are elsewhere fully treated with proper credit, and I allude thereto with the view of adding concurrent testimony that the original measurements were properly made and the results obtained were within the requirements of practical accuracy in such cases.

Regarding the means employed by Mr. Rafter to ascertain the dynamic conditions of flow, there are a number of features of which it would be interesting to learn more of the details. Such, for instance, as to how the summits of the piezometric columns were indicated for instrumental reading. Then as to whether the several stand-pipes were read simultaneously; or, if not, what time elapsed between the readings. It will be obvious that much of the value of these observations will depend upon the manner in which these features were carried into effect.

Although I believe and admit that the practice here described by Mr. Rafter is usual, I yet have grave doubts as to the reliability of piezometers when attached directly to the air valves of a pipe line long in use. As a means of determining the present internal condition of any particular air valve such an attachment would appear to be most efficient; but unless it were known to an absolute certainty that their internal conditions were identical each with the other, then it has always appeared to me that to predicate the internal physical condition of a long pipe line from the flow past orifices of unknown contour is an unreliable deduction. I should say in a case of this kind, where it may be fairly well assumed in advance that the conduit is obstructed by incrustations upon the interior surface, that the inner ends of the piezometers might better be inserted into the main body of the conduit, the internal ends of all the tubes to be at the same distance from the exterior of the conduit, as in this wise practically identical dynamic conditions would obtain.

As to the determination of the hydraulic gradient of the 24-inch section by means of ordinary spring pressure gauges, I have examined Mr. Rafter's paper diligently for a reference to the means employed for standardizing the gauges; but although the manner of checking their reading by independent observers is expressly set forth (which would appear to be necessary, as they must have been read to fractions of a pound, judged by the tabular deductions), there is but this statement as to the gauges themselves: "The gauges were attached to each air valve at the same time, and allowed to remain for half an hour."

Now, as a glance at the profile will denote the considerable fluctua-

tions in the total pressures required to be indicated by the gauges, this fact alone would demand that they should have had frequent and most accurate comparison with a reliable standard. If this were not done, then, in my opinion, but very little value may be given to this portion of the experiment. The fact that the gauges did or did not indicate the true conditions does not affect my present proposition; if they were not calibrated to every change of condition, then the result can only be accepted as hypothetical.

In this connection the admission of Mr. John R. Freeman, M. Am. Soc. C. E., in his discussion of my paper on "Proportional Water Meters," wherein he is an advocate of spring gauges for an analogous purpose, may not be inaptly quoted: "In any important work in either steam or water, all Bourdon gauges should be often tested. Mere comparison with a standard gauge is not fully satisfactory." And in this regard I presume to say that Mr. Freeman knows whereof he speaks; for although he has accomplished results in this direction approximating practical accuracy, and that, too, by scientific methods and approved apparatus, yet even these were open to adverse criticism.

That the Rochester conduit has undergone serious deterioration is not questioned, but as to the cause and location thereof, it is my contention that the present demonstration is not conclusive; that the case stands on the Scotch verdict, "Not proven."

The end sought by Mr. Rafter, as detailed in his second paper, was to increase the storage reserve of the reservoirs, and the exigencies of the case were such that almost any means would be tolerated to effect this end. The method evidently most prominently in mind for immediate application, both by citizens and experts, was to increase the time necessary to obtain a given quantity.

The manner here described of carrying this into effect seems to have been based upon the assumption that any diminution at or near the source of supply would cause the mains to "run partly full," with obvious results in the event of applying the direct pressure from Rush reservoir. The question here is, was the somewhat elaborate process applied by Mr. Rafter necessary? I am willing to go on the record as saying that, in my opinion, it was not; that if competent attendants had been placed at the discharging gates of Mount Hope reservoir, or better still at some lower portion of the hydraulic gradient beyond the principal distributing area, in telephonic communication with the city fire alarm, the valves carefully pinched down to a point where the draft there through became slightly less than the supply, and continually so maintained, then the same results would have been reached. By this method the minimum pressure throughout the city would have been constantly increased until merged into the maximum, while yet at any instant the full pressure might have been with safety applied for fire purposes. But what was the consequence of this "restriction" in actual

fact? Simply as already intimated, that each and every water-taker in a city of nearly 140 000 inhabitants, the just and the unjust alike, was peremptorily taxed that the storage reserve might be increased. The form of the tax here levied was in time; the monetary value of this will depend upon the wage earning capacity of Rochester's citizens. What this means may only be conjectured, even when we have Mr. Rafter's statement that the result of these restrictive measures was to decrease the consumption by nearly 2 000 000 gallons a day, that is to say, increase the former time necessary to obtain a given volume by from 30 to 40 per cent., or made it impossible to get such supply at all.

The summation of Mr. Rafter's opinions, however, has my particular attention, wherein he sets forth that by this method of restrictive supply the "general movement in favor of metering" was, fortunately for the public, presumably, headed off, "which, if carried out under existing conditions, would have aggravated a situation which is already sufficiently unsatisfactory."

The premise upon which I shall mainly rely in my further contention is this: that if the actual cost, due to the loss of time and personal inconvenience, to which the citizens of Rochester have been subjected by these restrictive measures, had been invested in water meters of any fairly reliable pattern, were they of the cheapest inferential Continental type or the most expensive positive system here in vogue, that then not only would there have been no temporary inconvenience, but there would immediately have been water enough and to spare; the pressure would have been restored and the future supply insured beyond all doubt. By this simple expedient every water-taker would have become an inspector. Instead of a handful of irresponsible employees acting as water-waste detectors, there would have been thousands of willing volunteers. And why? Because it would then have been a simple matter of selfish pecuniary interest on the part of every metered water taker. Human nature is the same the world over. It is not implied, nor does it follow, that because the segregated members of a community act with thoughtless disregard of others that therefore all are venal. Nevertheless, this hard, indisputable fact remains: that he who purchases by the sole measure of what he can take in the time at his disposal, will carry off more than if he had bargained to pay for bulk or weight. The proof of this assertion is on every hand; from the earliest evolutionary evidence of our ancestry, grabbing more than can be carried and snarling at the loss, to our modern teachers of morals who complacently latch down the spring closing valve that cool water may be ready to the cup, the principle is in all cases the same. And so it would be if you and I were provided with coal or gas, bread or champagne at so much per quarter, take what we like; the damper would not then be so carefully regulated; the extra jets would not be put out; bread would only be used for end pieces and corks would fly upon the slightest indication of las-

situde. Wherefore, I do not believe that we would be morally worse than at present; for the par value of the individual is the resultant of the society of which he is a factor. But in setting this, my opinion, with these generalities, as against the judgment of Mr. Rafter, I do not thereby wish to be understood as implying that even if he had held my undoubtedly extreme views on this subject, that he, per consequence, would or could have applied them in practice: because it is not neglected to be observed that too often the municipal engineer may be limited in his work by the judgment of higher municipal authority; be it always excepted, however, that he is seldom justified in the performance of a professional duty not warranted in its method and execution by the best practice of the hour.

But the lavish waste which so nearly resulted in a water famine in Rochester did not take place nor come upon it without ample notice from competent authority, as may be found in the annual reports of its long time Chief Engineer, Mr. Tubbs, who for years had been a conservative advocate of restrictive measures. Neither was the more or less brilliant idea of closing the spigot a growth of the year 1890; as may be judged by the following paragraph from a letter written by me and published in the Rochester *Daily Herald* of May 27th, 1889:

"In my judgment Mr. Kuichling is right in either of the two remedies which he proposed to your Special Water Works Committee. 'Good gracious,' you say to the first, 'and shall the pressure be reduced?' Why not, if you are already demanding more than the supply? Mr. Kuichling evidently recognizes a point you overlook, namely, that if you were supplied with twice your present volume you would doubtless double your wastage. This feature is already being considered here in New York, for when we shall have had the increased pressure of the new conduit, the 'consumption' of leaky pipes, faulty faucets, etc., is certain to reach high figures.

"So far as possible I endeavor to keep pecuniary motives in the background when I say, as a matter of concurrent judgment, that Mr. Kuichling's second remedy, namely, to meter the services, is the only true and satisfactory method, and that this is not theoretical or visionary has been proved times over.

"And the cost of the meter method of increasing your water supply by equalizing its disposal would not be the 'enormously expensive job to the city or its citizens' which you may think, and for this reason if no other, namely, that even if a portion of your services were metered the waste would be enormously reduced, because you will find that the great majority of your water takers are willing to pay for what they use; that such people in any case would not abuse their privileges; that the opposition, the growl, will be, as doubtless it now chiefly is, from those who are taking more than they are honestly entitled to."

I have purposely refrained from quoting the generally known data in

support of my position as to which is the better method, legitimate use by all or waste by all, for the particular reason that I have here to present a most admirable discussion, covering this phase of the subject, prepared at my request by L. N. Case, Esq., Secretary of the Board of Water Commissioners, Detroit, Mich. I applied to Mr. Case for these principal reasons, namely: that the relative conditions as between Rochester and Detroit are more nearly alike than any others of which I am aware; that meters and restrictive measures were applied there for the purpose of avoiding the duplication of force mains and pumps, and that Mr. Case is not only thoroughly conversant with all the available facts, but has the peculiar skill of compressing such matter into clear and compact form.

To recapitulate in brief, my criticisms in respect of Mr. Rafter's papers are these: That while the methods which he employed may have been generally correct, the apparatus itself was not adequate to the requirements of the case nor in touch with well known modern practice; and that his opinions as to the probable consequence of metering are fully controverted by good and sufficient evidence.

Without pointing the moral which you will the better apply, I take the liberty of concluding in the following words from Judge Stallo's preface to his "Concepts of Modern Physics":

"It is an old truth, which, however, is too often lost sight of, that many of the questions of science and philosophy remain unanswered, not by reason of the insufficiency of our knowledge, but because the questions themselves are founded upon erroneous assumptions and require answers in irrational or impossible terms."

L. N. Case, Board of Water Commissioners, Detroit, Mich.—For the purpose of properly estimating the waste prevalent in the City of Detroit, I will state that the population of the city in 1888 was 192 729, and the daily average consumption 39 397 716 gallons or 204 gallons per capita; a waste, allowing for a generous use, of 150 gallons per capita, or nearly 30 000 000 gallons per day. In 1890, two years thereafter, as a result of the introduction of restrictive measures, the following data are offered: Population of city, 214 122; daily consumption, 33 208 067 gallons, or a per capita supply of 155 gallons, and a saving of about 12 000 000 gallons of water daily, and of about $20 a day or $7 000 annually in fuel alone. This, however, does not give the real saving effected. Several times in the winter of 1888–89 over 50 000 000 gallons of water were pumped into the city daily, and the demand even then was by no means satisfied, as many complaints reached us of a short supply in the upper and western portions of the city. It was then demonstrated that our capacity to supply was exhausted, or rather its limit reached.

I will explain by saying that our pumping station is 4 miles up the river

with two 42-inch force mains leading therefrom into the city, one for the low and one for the high service. Our average daily consumption had increased 3 000 000 gallons each year for several years, and of course was gradually increasing. The necessity for another force main, and another engine, an enlargement of our present engine house or the building of a new one, and other attendant expenses accompanying such construction, was conclusive. An estimate was made of such extensions, which amounted to about $600 000.

Had the Board concluded to enter into such enlargement of the works, bonds would have had to be issued bearing 4 per cent. interest, entailing an annual expense thereafter of $24 000, to say nothing of the constant depreciation in the value of the plant, as well as the increased expense for fuel, salaries of engineers, lubricators and other supplies, which would amount at least to $11 000 per annum. I will give as my basis for this calculation, the fact that the total expense at the pumping station in 1890 was $54 433.49 for three engines and never but two of them running, so that an estimate of the above increase is a modest one to say the least. Here then is an annual expense of $35 000, which an enlargement of the plant would have forced upon the Board, or rather upon the citizens of Detroit.

At its meeting in February, 1889, these facts were presented and several other facts bearing upon the question of waste, and comparisons offered between Detroit and other cities that had adopted measures to prevent waste. The Board, after carefully considering these facts, adopted a resolution to at once enter upon an active campaign against a waste that had become actually appalling, and directed their Secretary to adopt such measures as were reasonable and lawful that would accomplish their purpose.

Now, as to the measures adopted, they were by no means novel or unusual, and were simply those of house to house inspection and the introduction of meters. Could meters have been universally introduced, the inspection of premises would have been unnecessary, and at best accomplishes but little. Innumerable leaks, of course, are discovered, and require to be repaired, but the willful, extravagant, and utterly useless running of water from all classes of fixtures, through carelessness, and often a mistaken idea that such streams cleanse and purify the sewers, can only be controlled and regulated by the placing of meters. This of itself is a sufficient reason for their adoption, and yet another appeals to me with almost an equal force.

Estimating the quantity of water consumed, even with the best of intentions and ability on the part of the assessor, is after all only guesswork. This is not simply an assertion, but is the result of actual experience. The following table is prepared from actual facts upon the books of this office, and is based upon the consumption of water which

was being used as developed by the meter, and upon the assessments which were paid before the water was metered:

Consumers.	Monthly Consumption as per Meter.	Monthly Assessment.	Paid for 1 000 Gallons.
A	583 500 gals.	$7 50	$1\frac{1}{4}$ cents.
B	132 000 "	2 00	$1\frac{1}{2}$ "
C	3 429 803 "	36 66	1 "
D	531 375 "	33 33	$6\frac{1}{4}$ "
E	185 250 "	13 67	$7\frac{3}{8}$ "
F	2 697 831 "	119 16	$4\frac{3}{8}$ "
G	472 201 "	39 66	$8\frac{3}{8}$ "
H	259 312 "	17 50	$6\frac{3}{4}$ "
I	138 850 "	28 33	20 "
K	727 125 "	50 00	$6\frac{7}{8}$ "
L	2 127 050 "	53 33	$2\frac{1}{2}$ "
M	270 750 "	37 66	14 "
N	1 352 850 "	142 00	$10\frac{1}{2}$ "
O	462,818 "	43 00	$9\frac{1}{3}$ "

The parties "C" and "D" are engaged in the same business, competing for the same trade, and yet "D" was handicapped by being obliged to pay, in the same city and under similar circumstances, over six times as much for water for manufacturing purposes as "C" did. The party "I" is a miller, and his uses were of a mechanical nature almost entirely, and easily estimated, and it was proved that he was paying exactly right, as 20 cents per 1 000 gallons, when estimated, was then the rate charged by the Board.

As a result of the saving thus made, the Board have reduced their meter rates from ten cents per 1 000 gallons to three and one-third cents to all consumers, and in addition have abrogated the charge for hose use for lawn and street sprinkling purposes, the assessments upon which, the year previous to such action of the Board, amounted to over $20 000.

The placing of meters has been with us, and will be everywhere, a great saving individually and collectively. For instance, the present receipts for the entire metered consumption is not over two-thirds of what it would be under the assessment plan, and the amount of water consumed not over one-fourth. The result of the introduction of meters in the City of Detroit can best be shown by the following comparison:

Had the Board concluded in 1888 to make the contemplated enlargement of the works instead of introducing measures of restriction, the annual expense caused by such enlargement, as already shown, would have been at least $35 000, or for three years $105 000, with an unestimated loss for wear and tear, and no reduction in rates. The total expense for the introduction of meters has been up to October 1st, the present month, $50 812.50, with an estimated sum for the three months thereafter will make $56,000.

But mark the difference between the two expenses! The former, of $35 000 per annum or $105 000 for the three years, would have been an absolute expenditure; while of the latter at least 85 per cent. is still in existence, and is a valuable part of the plant.

J. Nelson Tubbs, M. Am. Soc. C. E.—The methods described in Mr. Rafter's paper for reducing the consumption of water in the City of Rochester, while confessedly not new or original, may be regarded as a wise provision to tide over a temporary crisis, and without doubt accomplished the purpose of temporarily preventing the further depletion of the reservoirs. The lack of vigorous action on the part of the municipal authorities having the control of the water department, in failing to provide an abundant temporary supply of water for the city from one of several possible near sources, left no alternative to the engineer but to restrict the use of water to such an extent as would prevent its utter exhaustion from the reservoirs. In this view of the case the action of the engineer is to be commended, while the want of prompt and right action on the part of the municipal authorities, whereby such drastic measures in the way of restrictive use became necessary, is to be seriously reprobated. The adoption and continuance of these restrictive measures have proved so annoying, vexatious and threatening to manufacturers and other citizens that private sources of supply have been secured by many of them, thus reducing the consumption from the city works to the extent of at least one and one-half million gallons per day, involving the consequent loss of revenue to the city. It has also involved the necessity of sprinkling the streets with the sewage laden water of the Genesee River. It has had a tendency to restrict the introduction of new manufacturing establishments, the opening of new streets, and the erection of new dwellings; and it has prevented the proper flushing of sewers and drains, and has thus proved detrimental to the sanitary condition of the city. I cannot, therefore, concur in the wisdom of the further suggestion of the paper under discussion, that by the continuance of these restrictive measures the reservoirs may be kept full, and "aside from street and lawn sprinkling, the necessary legitimate uses of water can be supplied for two or three years, during which time the additional supply construction may be completed." The many and complex interests of a city are so injuriously affected by a scarcity in the water supply for a series of years, that no make-shift should be tolerated which looks to the continuance of a system alike perilous to the business, prosperity, comfort and health of the municipality.

Some of the conclusions of the writer of this paper I am impelled to call in question. These are based upon a doubt as to the original capacity of the conduit to discharge at the rate of 9 000 000 gallons per day, from the fact that the discharge is at the present time but 7 000 000 gallons per day. The method of determination by which it was found

to deliver the larger quantity in 1876, was exactly the method employed in 1890, when it discharged the smaller quantity.

The evidence that the said conduit did originally discharge 9 000 000 gallons per day is of the highest character. In 1876, I was chief engineer of the water-works in question, and the late Lorain L. Nichols, a very competent man of large experience, was one of my assistants. During the filling of the reservoirs and the months following, Mr. Nichols was directed by me to make such careful measurements and gaugings of the reservoirs as would enable him to determine very closely the approximate flow of the conduit. He did this on at least four different occasions, the records of which, in his own handwriting, are now on file in the Water Department at Rochester, and his conclusion from these experiments was, that the flow was substantially 9 000 000 gallons per day. I, therefore, regard it as much a definitely settled fact that the flow in 1876 was 9 000 000 gallons per day, as it is a fact that at the expiration of sixteen years, in the year 1890, the flow was but 7 000 000 gallons per day, and both facts were determined in the same way, and are based upon the same class of evidence, to wit: the rise of water in the reservoir under the influence of the flow of a full conduit.

From what has been said, it may be seen how difficult it would prove to determine when, or at what moment, any statistics published in the annual reports of the Rochester Water Department, based upon the earlier determination of the capacity of the conduit, ceased to be entirely true. Only two facts are known, to wit: In 1876, and for some years thereafter, I am convinced by personal observation of the conduit, the discharge was substantially 9 000 000 gallons per day. In 1890 the flow was 7 000 000 gallons per day. When did it cease to be the greater and become the less quantity? The imperative necessity that has existed for the past three years, that there should be no interruption in the flow of water for a single hour which could be avoided, has prevented such an examination as would determine the cause of this diminution of flow. Presumably, however, the decrease was a gradual one, and so gradual as to be unsuspected, and not such a sudden and abrupt one as would have at once attracted attention. History repeats itself in these matters. So far as I know, the history of all iron pipe water mains has been a gradual and more or less rapid decrease in their carrying capacity by the formation of tubercles, often accompanied with the growth of extensive vegetable life, the latter of which in the form of spongilla in large quantity has been found recently in the cast iron pipe forming a part of the Rochester conduit, by Mr. Kuichling, a member of this Society, on removing the dome of a 24-inch gate for repairs, the details of which are given in his annual report recently published. I can see in all this no reason to question the large co-efficients used in modern formulas for large, new and clean pipes, but it emphasizes the fact that the pipes will not always remain new and clean, in which case the large

co-efficients are no longer applicable, or, in other words, that to approximately determine the flow of a pipe at the end of twenty years' use formulas with relatively small co-efficients should be used.

W. N. RADENHURST, M. Am. Soc. C. E.—Mr. Rafter, in his paper, states in his comparisons of the results of tests made: First. That the "average rate of hydraulic grade in the 36-inch wrought iron pipe is 50 per cent. greater than it should be for clean pipe with the observed discharge." And again, "That the excessive resistance prevailing in the 24-inch pipe at the present time, is mostly confined to the wrought iron section, the excess in the cast iron being, generally speaking, only such as may be reasonably expected in pipe a long time in use."

As no 36-inch cast iron pipe exists on the line, all criticism must be directed to the 24-inch conduit alone. Attention may, however, be called to the fact that the hydraulic grade line found the same day is practically a straight line, and that there are no very marked irregularities in loss of head in this section.* As to the irregularities on the 24-inch pipe pointed out by Mr. Rafter in his basis of comparison, the question arises whether such a marked difference in loss of head would be discovered, if the pressure observations had been made with a suitable mercury gauge.

The engineer who made the original gaugings and calculated the inflow into Rush Reservoir, the late L. L. Nichols, has left in his handwriting carefully prepared notes of the gaugings taken by him at Rush Reservoir on four different occasions, the least of which gives about 8 000 000 gallons, and the greatest about 10 000 000 gallons in twenty-four hours. That it now delivers only a trifle over 7 000 000 gallons daily must also be conceded. A reduction in delivery must accordingly be acknowledged, and I desire to discuss the question on that basis. The reason for this diminished delivery may, perhaps, be due to obstructions at a number of places, since the diagram of the several hydraulic grade lines does not show a sufficient fall between any two consecutive air valves to account for the entire difference in discharge. The probable causes are tubercular formations and the growth of spongilla or similar organisms. Mr. Rafter is inclined to the belief that the wrought and not the cast iron pipe is to be blamed for the failure in delivery. This may be so; but that apparently well coated cast iron pipe deteriorates, and often deteriorates very rapidly, is, nevertheless, a fact of which ample demonstrations have been given in our professional literature.

The probings made by Chief Engineer Kuichling in the 36-inch wrought iron pipe at air valve No. 53, and in the large tapering casting inserted in the 24-inch cast iron pipe at Rush Reservoir, and fully described by him in his last annual report (1890–91), gave no evidence of "tuberculation by rust, mineral incrustation," etc. He did, however, find a large growth of spongilla on the interior surface of the 24-inch

* See profile accompanying the discussion on Mr. Rafter's paper already submitted to the society by Mr. Kuichling, M. Am. Soc. C. E.

cast iron effluent pipe at Rush Reservoir. In the city work at Rochester it has been the practice for over a year to carefully examine the interior surfaces of all mains, wherever the same may be cut for insertion of special castings, or for making extensions, etc., and to make notes of the conditions found and preserve specimens of the broken pipe, and the following table showing the condition of pipes of different ages, selected from a number—all Hemlock mains—may be of some interest on the question of deterioration.

No.	Diameter of Pipe. Inches.	Street.	Location.	Date of Laying.	Date of Examination.	Years.	Conditions.
1	4	Stone St.	Corner of Ely St.	1874	Nov. 8, '90	16	Badly corroded, large tubercles half an inch thick, covering surface coating, destroyed. This pipe was made at one of the foundries that furnished the 24-inch cast iron conduit pipe.
2	12	Genesee St.	50 feet South of College St	Sept. 15, '80	Aug. 25, '91	11	Large tubercles, over three-eighths of an inch, and thick mat of spongilla.
3	6	West St.	75 feet North of Lorimer St...	Aug. 31, '87	Oct. 28, '91	4	A few tubercles and clots of rust —coating good between.
4	10	Lake Ave.	At Clay Avenue	Oct. 27, '88	Oct. 27, '91	3	Tubercles sparse, but of fair size, pipe coating between tubercles glossy and smooth.

Specimen No. 2 was particularly luxuriant, both as to the thickness of the tubercles and the strong growth of spongilla. Specimen No. 1 was cut out of pipe laid sixteen years ago, and was cast at one of the foundries that supplied the 24-inch pipe laid in the conduit line. It doubtless was treated to the same coal-tar pitch bath as the large pipe. By parity of reasoning, if rust tubercles have formed on the inside of the small pipe, which has actually been seen, why not form on the large pipe, which has not yet been examined?

It is generally assumed that the coal-tar pitch coating as applied to cast iron water pipes by most of the foundries in this and other countries, is a permanent protection to the iron against rust. It certainly does not appear to act in this manner in all cases. The writer is informed that Messrs. R. D. Wood & Co. did some years ago in their foundry at Florence, N. J., use a mixture of 20 per cent. of pure linseed oil with the coal-tar pitch, but does not know whether this practice was continued.

Most foundries use the coal-tar pitch alone. A permanent coating seems to be almost as vital to the life and usefulness of the pipe as the quality and strength of the iron; and it is respectfully suggested that the members of the Society who are interested in this branch of the profession, should, from their experience and observation, give their views as to what change could be effected in the composition of the coating material, so as to render it more durable than it is found to be in practice. The coating as applied to both exterior and interior surfaces of the wrought iron 36 and 24-inch pipe used in the conduit was composed of about equal parts of refined Trinidad asphaltum and coal-tar pitch, the proportions being somewat varied in cold weather by an increase in asphaltum, as the coal-tar pitch had a tendency to make the mixture brittle.* The testimony of those who have seen the exterior of the wrought iron conduit pipe is to the effect that the coating is still in a good condition (the same, however, is mainly true in the case of the cast iron), but unfortunately in no case has the interior of the pipe been seen.

In connection with this question of coating wrought iron, the writer personally examined a case where a 24-inch wrought iron pipe used as a flume for conveying water, and which was coated with "Black Parafine Varnish," ordinary boiler-maker's composition, was exposed after seventeen years' life, it having been laid in 1874 and exposed April 3d, 1891. The pipe coating showed a bluish black color, and exhibited no signs of corrosion. Judging from the exterior, as seen, the question may be asked: Is the interior asphaltum coating a preservation against corrosion? The members of the Society are respectfully requested to send in contributions also on this point.

It may be of interest to state that Mr. Nichols made what is believed in this country to be the first examination in the nature of accurately determining "Discharge from Drainage Basins." He acted as Mr. Jervis' assistant, and was for two years gauging the flows of Eaton and Madison Brooks, for feeding the summit level of the Chenango Canal.†

George W. Rafter, M. Am. Soc. C. E.—In closing the debate I may first call attention to a fact that has been apparently lost sight of by some of the gentlemen participating, namely, that the tests briefly recorded in the paper on the Hydraulics of the Hemlock Lake Conduit, etc., were not undertaken originally for the purpose of either discovering new principles in hydraulics or confirming old ones, but merely for the purpose of finding out by the application of known principles why the Hemlock Lake Conduit of the Rochester Water Works only delivered in the summer of 1890 about 73 per cent. of what it had been claimed to be doing a little over a year before. Instructions to begin the tests were given by the Executive Board to the writer on July 7th, 1890. At the

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* For a further statement see Report of J. Nelson Tubbs, M. Am. Soc. C. E., for year ending January, 1874, page 25.

† See Report of J. B. Jervis, dated January 14th, 1836. Reported in Senate Doc., No. 52, N. Y. S., for the year 1838, p. 209; also in State Engineer's and Surveyor's Report, State o N. Y., for 1862, pp. 203 and 204.

same time it was requested that the work be completed and the results presented in not exceeding thirty days from that date.

On looking the matter up it was found that the original construction bench marks were nearly all obliterated and the records were deficient in many respects. It appeared necessary, therefore, to make a new profile with careful location of all the details. The measurements were made with a 100-foot steel tape, and the locations of the air valves are believed to be fairly accurate to the nearest foot. The new series of benches have been referred to in the paper.

Reference has been made in the discussion to my results as not scientifically correct. The writer of this statement probably means minutely correct, in which case it becomes at once evident there is as yet no science of hydraulics. An engineer is not necessarily a man of science in the sense of always working to the second, third or fourth decimal. As one who "adapts the forces of nature to the comfort and convenience of man," he will often be obliged to use the things at hand; and generally he is the best engineer who uses the material at hand in the shortest time for the attainment of the desired result.

In writing my papers, details have been purposely omitted as likely to be of little interest to the Society. Inasmuch, however, as the detail has been asked for, I will endeavor to give such as seem necessary in reply to the discussion.

It is conceded on my part that whatever the actual performance of the Rochester conduit may be, its theoretical capacity is in the vicinity of 9 000 000 gallons daily; but the realization of this capacity in actual performance would imply that theoretical conditions were complied with in its construction. The positive statements to the contrary by intelligent persons should be taken account of in discussing the question, and it is because of the existence of such information that I have doubted the correctness of the original determination.

In reviewing the remarks of Mr. Kuichling I will, for convenience, use the same heads which he has himself used, namely, first, second, third, fourth.

(1) It is admitted that the observations given in Table No. 1 were not simultaneous; they were not even all taken on the same day. Indeed I know of no practicable way by which they could be all taken simultaneously, although they might possibly all be taken on the same day. As shown by Table No. 1 and the profile Plate XII, there are sixty-nine air valves between Rush Reservoir and Hemlock Lake, and sixty-nine simultaneous observations would imply at any rate sixty-nine observers, each with at least two assistants. However, at about ten valves the conditions are such that two observers would be required with four or five assistants. Simultaneous observations would therefore imply say seventy-five observers with one hundred and sixty assistants, or a total of two hundred and thirty-five men in all. Before the work could be properly performed, all of these persons would need special instructions

by actual practice in the field. Mr. Kuichling's objection that the observations were not taken simultaneously may be therefore dismissed without further consideration.

Mr. Kuichling has compiled in his Table A the record of work from day to day, and about what can be done by one party is there indicated at various parts of the line. From six to eight fully equipped parties would be required for doing the work in one day, and this, while not impossible of attainment, would also be somewhat difficult.

In reference to these observations it is stated that they were begun, as indicated in the appendix, on July 25th, 1890. At that time repairs of a serious leak at about Station 70 were in progress, and it was found that the effect of the centrifugal pump in use for draining the excavations was clearly felt in causing a pulsation in the flow of the conduit. This was especially marked on July 26th and all the observations taken during the working hours of these two days were accordingly rejected. During the night of July 26th and a portion of the morning of July 27th, while the said pump was not in operation, a series of observations were taken at Air Valves 83, 84 and 85, in order to determine whether pulsations took place when there were no such disturbing influences as had existed during the working hours of July 25th and 26th. The result of these observations was as per following:

TABLE No. 3.

July 26th and 27th. Hours.	Elevation of Piezometer at Air Valve 83.	July 26th and 27th. Hours.	Elevation of Piezometer at Air Valve 84.	Elevation of Piezometer at Air Valve 85.
July 26, 7 P. M.		July 26, 7 P. M.		
7.30 "	380.72	7.45 "	381.23	381.52
8 "	380.72	8.15 "	381.23	381.47
8.30 "	380.69	8.45 "	381.17	381.51
9 "	380.70	9.15 "	381.16	381.50
9.30 "	380.71	9.45 "	381.17	381.48
10 "	380.74	10.15 "	381.17	381.48
10.30 "	380.73	10.45 "	381.20	381.47
11 "	380.73	11.15 "	381.21	381.47
11.30 "	380.73	11.45 "	381.16	381.50
12 "	380.70	July 27, 0.15 A. M.	381.17	381.49
July 27, 12.30 A. M.	380.71	0.45 "	381.17	381.44
1 "	380.71	1.15 "	381.17	381.47
1.30 "	380.71	1.45 "	381.18	381.47
2 "	380.71	2.15 "	381.18	381.47
2.30 "	380.73	2.45 "	381.18	381.47
3 "	380.73	3.15 "	381.18	381.47
3.30 "	380.73	3.45 "	381.18	381.47
4 "	380.725	4.15 "	381.175	381.47
8.30 "	380.73	8.25 "	381.21	381.57
9 "	380.73	9.05 "	381.22	381.51
		11.15 "	381.18	381.49

Taking the means we obtain:

Grade.

Air Valve 85 — 0 — 381.474
(0.295) — 0.4307
Air Valve 84 — 685 — 381.179
(0.456) — 0.4449
Air Valve 83 — 1 025 — 380.723.

Mr. Kuichling has given in his Table A the series of observations (*a*), (*b*) and (*c*) for July 26th, at these valves. All observations as here tabulated for July 25th and 26th, have been rejected by reason of known disturbance from the pump already referred to.

In the same way other observations have been rejected for good and sufficient reason. Relative to this matter of rejecting observations, I may refer to the dictum of Mr. Wright. He says :*

"In making a series of observations the observer is given full power. He can vary the arrangements, choose his own time for working, reject any result or set of results ; he can do anything, in fact, that in his best judgment will tend to give the best value of the observed quantity."

In reference to the rise of water surface at Rush Reservoir, a study of the matter with a profile platted at large scale shows that this also is not of such significance as to in any degree vitiate the conclusions.

(2) The fluctuations referred to by Mr. Kuichling were frequently observed, and the recorded elevations in the notebooks show the mean of the fluctuations at the time of making the observations. Usually the range was from 0.02 to 0.05, and, except at air valves 55, 56 and 57, very rarely as much as 0.07, although 0.10 has been observed on a few occasions. The fluctuations were mostly followed by periods of rest, during which the level of water in the piezometer was nearly constant, and to which it may be said to return after one of the periodic fluctuations. With very short distances between air valves an error in grade may occur by reason of these fluctuations, but, so far as the final result on the long lines is concerned, the fluctuations have practically no significance. It will be observed that my conclusions in the paper are based entirely upon the results for the long line, and it is these results that Mr. Kuichling must show untrue before the conclusions of my paper are in any way impeached.

At air valves 55, 56 and 57 a record was kept for a number of days, but the observations were not reduced last year for lack of time, and inasmuch as the notes are not now in my custody I have as yet had no opportunity of reducing them. The relatively great and sudden fluctuations at air valves 55, 56 and 57 may to some slight extent be due, as suggested by Mr. Kuichling, to disturbances by reason of the progress of repairs. They occurred, however, not only at times when no repairs were going on, but also when the conduit was found by trial to be free of air. They are, I believe, largely due to disturbing influences in the way of obstructions in the conduit itself in the vicinity of air valve 56. The statement of the keeper of Rush Reservoir in regard to discharge of air, as made to me, applied only to periods immediately following the emptying and refilling of the line.

There is, however, no question as to the freedom of the conduit

* A Treatise on the Adjustment of Observations. By T. W. Wright. See Note II on the Rejection of Observations, page 131.

from air during the period covered by these tests. Special care was exercised on this point, not only by observation when opening air valves for the tests, but by frequently opening valves at critical points where the tests were not in progress in order to insure such freedom.

(3) Taking up the question of pressure gauges as used from air valves 46 to 23, it may be said that the four gauges used on August 5th and 6th were from the Utica Steam Gauge Company, while the two in use August 15th and 16th were made to special order by Schaeffer and Budenburg. The history of the matter is as follows: Several new Utica Steam Gauge Company's gauges, purchased for another purpose, were on hand at the time of beginning these tests, and it was assumed that an ordinary pressure gauge would answer the purpose of determining whether there were special obstructions at particular points. It was further assumed that even though the gauges were not absolutely standard, so long as the error remained the same or nearly the same at every point, the indication of rate of grade between consecutive points might be accepted as reasonably accurate. The truth of this latter assumption, which is the important one, is shown by comparing the results between air valves 35 and 29 as obtained August 5th and August 16th, respectively. The gauges used August 5th are known to have been at least a pound in error, yet the grade obtained on that day bears the proper relation to the grade of August 16th. The Utica Steam Gauge Company's gauges, however, were not satisfactory, and the work was therefore stopped on August 6th and a special order given to Schaeffer and Budenburg to make a pair of gauges which would stand the pressures required. The gauges received from them were the Nos. 1 076 544 and 1 076 545, referred to by Mr. Kuichling. They were tested together on August 14th, 1890, giving the first record, tabulated by Mr. Kuichling. They were again tested August 23d, giving the second record of Mr. Kuichling's table. It was fully understood at the time of making these tests that the Woodbury Engine Company's test gauge was far from correct, and the record of that gauge has no significance other than as showing its incorrectness. These tests of gauges were made at the Woodbury Engine Company's shop by reason of a pump and convenient appliances for attachment of gauges being at hand there. Schaeffer and Budenburg certify in writing that the two gauges were made to a special order, were accurately adjusted to standard and were warranted to stand water pressure up to 150 pounds. The tests made both before and after their use in the Rochester conduit justifies this statement on their part.

Mr. Kuichling refers to his Table A, and diagrams, Plate XIII, as illustrating the uncertainties attending the use of pressure gauges. I have already stated that a considerable portion of the data which he has compiled in these two exhibits was rejected because of known inaccuracy. The probable limit of error in the matter is, I believe, properly indicated in the foregoing explanation.

(4) As to the relation between nominal diameters and actual diameters I would refer to the annual report of 1876, which states that the diameters were determined at 24 inches and 36 inches respectively, from careful measurements made during the progress of the work.

This question was, however, given attention at the time of making the tests. The 24-inch cast iron pipe was cast, I believe, at three different foundries, and pieces of the same class from different foundries, as measured last year, gave different results. The sections of wrought iron pipe still in stock were found to vary somewhat, and there was no way of treating the matter except to assume the nominal diameter, and variations from other causes were probably greater than those due to this assumption. The figures given by Mr. Kuichling indicate that, generally speaking, the variations in diameter are in the right direction to favor the pipe.

Mr. Kuichling is in error in stating that the method used in changing the direction of the pipe was not taken into account. It was not only considered carefully, but in my percentage comparisons, allowances have been made in excess of the real necessities of the case, as is shown by what follows:

Let us estimate the amount of head which is probably consumed in overcoming the various resistances due to bends and angles in this pipe, making use of the method of Weisbach, found in Neville's Hydraulics,* Section XI, where is given a convenient epitome of the several experimental researches on the subject. Weisbach's formula apparently takes into account all the several elements of the problem. It is, moreover, based on experiments with small pipes, and it may be safely assumed that the actual resistance from bend in pipes 2 and 3 feet in diameter will not be greater than is indicated by the formula.

The final expression for the loss of head due to bends in circular pipes is:

$$h_b = \frac{\phi}{180} \left\{ 0.131 + 1.847 \left(\frac{d}{2\,p} \right)^{\frac{7}{2}} \right\} \frac{v^2}{2g} \ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which

h_b = head in feet consumed in overcoming the special resistance due to any given bend or curve;

ϕ = the deflection angle;

d = the diameter of the pipe in which the bend is inserted;

and p = the radius of the axis of the bend.

For the 36-inch pipe two separate cast iron bends were provided, namely, 8 degrees and 15 degrees. These are what may be termed short bends, the radius of the axis being the semi-diameter of the pipe. Let us apply formula (1) to the 15-degree bend.

With a discharge of 6 700 000 gallons in twenty-four hours $v = 1.467$

* "Hydraulic Tables, Co-efficients and Formulas, etc." By John Neville. Third Ed., 1875.

linear feet per second. For convenience we will take it at 1.5. We have then for the 15-degree bend:

$$hb_1 = 0.0059.$$

If we compute the value of h_b for the 36-inch (8-degree) bend, we find:

$$hb_1 = 0.00316.$$

Table No. 4 gives the number of bends on the 36-inch pipe, and there was one of 40 degrees at station 493 + 65. This was a special of 20 feet radius, made, probably, of about the form shown in Fig. 1.

Formula (1) for this "special" gives

$$hb_3 = 0.00002 -.$$

In the same way, the formula gives for bends of intermediate degrees of deflection a nearly inappreciable loss of head. Table No. 4 gives in detail all the bends on the 36-inch pipe. In the column of "Resistance allowance" is given, without actual computation for every case, what may be considered the reasonable allowance for each bend.

TABLE No. 4.

Serial Number.	Station.	Degree.	Horizontal or Vertical.	Remarks.	Resistance Allowance.	Serial Number.	Station.	Degree.	Horizontal or Vertical.	Remarks.	Resistance Allowance.
										Br't for'd.	0.1745
1	79 + 03	14°	*H*	*........	0.006	31	355 + 00	10°	*V*	*........	0.0045
2	82 + 70	14°	*V*	*........	0.006	32	357 + 00	20°	*V*	*........	0.0250
3	83 + 00	14°	*V*	*........	0.006	33	370 + 72	15°	*V*	Special†	0.006
4	100 + 73	13° 53′	*H*	*........	0.006	34	371 + 72	10°	*V*	Special†	0.0045
5	161 + 00	15°	*H*	*........	0.006	35	386 + 43	19°	*H*	Hub‡	0.0250
6	166 + 85	15°	*H*	*........	0.006	36	390 + 36	9°	*V*	Hub‡	0.0045
7	167 + 15	15°	*H*	*........	0.006	37	393 + 40	13° 30′	*V*	Hub‡	0.0060
8	191 + 50	28°	*H*	*........	0.010	38	395 + 65	9° 30′	*V*	Hub‡	0.0045
9	221 + 40	12° 20′	*H*	Special†	0.005	39	411 + 00	2° 30′	*H*	*........	0.0001
10	221 + 75	8°	*V*	*........	0.004	40	417 + 00	10° 20′	*V*	*........	0.0045
11	249 + 00	10°	*V*	Special†	0.004	41	419 + 30	10° 20′	*V*	*........	0.0045
12	263 + 23	8°	*V*	Hub‡	0.004	42	423 + 60	15°	*V*	*........	0.006
13	273 + 13	15°	*V*	*........	0.006	43	424 + 05	15°	*V*	*........	0.006
14	273 + 70	15°	*V*	*........	0.006	44	432 + 00	13½°	*V*	Hub‡	0.006
15	274 + 00	8°	*V*	*........	0.004	45	432 + 51	8°	*V*	Hub‡	0.004
16	275 + 20	8°	*V*	*........	0.004	46	436 + 00	8°	*V*	Hub‡	0.004
17	283 + 20	8°	*V*	*........	0.004	47	437 + 00	8°	*V*	Hub‡	0.004
18	312 + 58	15°	*V*	*........	0.006	48	445 + 00	6°	*V*	Hub‡	0.003
19	318 + 00	7°	*H*	*........	0.003	49	447 + 50	7°	*H*	Hub‡	0.004
20	318 + 15	15°	*V*	*........	0.006	50	461 + 50	30°	*H*	Special†	0.0005
21	319 + 65	15°	*V*	*........	0.006	51	466 + 25	23° 20′	*H*	Special†	0.0004
22	327 + 00	7°	*H*	*........	0.003	52	486 + 16	15°	*V*	Hub‡	0.006
23	333 + 10	12°	*V*	*........	0.009	53	486 + 75	30°	*V*	Special†	0.0005
24	333 + 70	8°	*V*	*........	0.004	54	487 + 15	11½°	*V*	Hub‡	0.005
25	341 + 00	15°	*H*	*........	0.006	55	488 + 50	20°	*V*	Special†	0.0004
26	342 + 30	15°	*V*	*........	0.006	56	490 + 00	16°	*H*	Hub‡	0.007
27	344 + 00	10°	*H*	*........	0.0045	57	493 + 23	20°	*V*	Special†	0.0004
28	347 + 00	18°	*V*	*........	0.020	58	493 + 65	40°	*V*	Special†	0.0015
29	349 + 00	8°	*H*	*........	0.004	59	494 + 12	8°	*V*	Hub‡	0.004
30	354 + 50	8°	*H*	*........	0.004	60	496 + 00	11°	*H*	Bend*	0.005
				For'd	0.1745					Amount.	0.3313

* Record does not indicate what was used.

† As per Fig. 2, with 20 feet radius.

‡ Special cast iron bend with radius of axis equal to semi-diameter of pipe.

In assigning values in the column of resistance allowance it is assumed that at places where the deflection is either 8 or 15 degrees the special cast iron bends were used. At odd angles where no indication is given, I have used a large enough value to cover an abrupt angle.

We thus determine that 0.3313 feet is the approximate theoretical value of the resistance due to bends in the 36-inch sections with a daily delivery of 6 700 000 gallons.

I have never seen any record as to the bends in the 24-inch wrought iron pipe, and am unable therefore to state the losses in that portion of the conduit. With a higher velocity and smaller diameter the effect of bends in it will, of course, be relatively much greater, but a very casual examination of the question will convince one that friction in bends does not explain the excessive resistance found in that section.

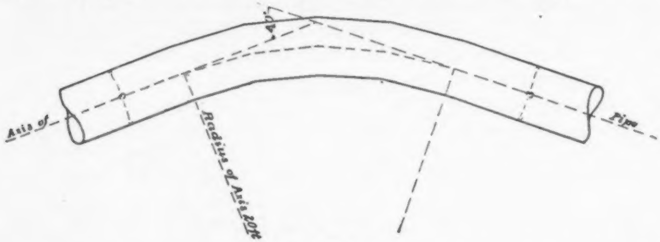


FIG. 1.

In order to compare the resistance in the whole conduit as actually determined by the tests with that in theoretically perfect pipe, the value of h'' was computed in the formula—

$$h'' = v^2\left(4m\right)\frac{l}{2gd} \quad \dots\dots\dots\dots\dots\dots (2)$$

in which

h'' = the loss of head due to the various frictional resistances in a thousand feet.

v = velocity in feet per second = 1.467 for the 36-inch pipe when discharging 6 700 000 gallons in twenty-four hours.

m = a co-efficient, derived from Mr. Fanning's diagram.*

For 36-inch pipe with velocity of 1.467 per second we may take $m = 0.00448$. l = length in feet = 1 000 feet. d = diameter in feet = 3 feet.

Whence for the 36-inch pipe $h'' = 0.199596$ = say, 0.2.

This represents the result of reliable experiment as to loss of head per 1 000 feet for a daily discharge of 6 700 000 gallons in pipes 36 inches in diameter; and it is clear, since the effect of bends has been found so slight, that this value of h'' could be fairly used for the percentage comparisons as given in the summary to the paper. In order, however,

* Plate XI, Vol. XIX, of the Transactions of the Society.

that I might do the conduit no injustice, I have used 0.3 in making the percentage comparisons for this sized pipe. In the same way a theoretical value of $h'' = 1.60$ was obtained for the 24-inch pipe and 1.75 used in making the comparisons. There is no reason, however, why the comparisons cannot be legitimately made with the values 0.2 and 1.60, and these values will accordingly be used for such purpose for the balance of this discussion.

Mr. Kuichling's remarks on the question of bends can only be taken as meaning, that he is disposed to explain a large portion of the excess loss in the 36-inch pipe at any rate as due to the bends. In the original computation for a 7 000 000-gallon conduit an addition of 0.267 feet was made to the diameter on account of the supposed considerable influence of bends in the upper section; while in the lower section only 0.009 feet was added for the same reason. The clear indication at the present time is that there is a lack of proportion between the 36-inch and the 24-inch sections of this conduit. The discharging capacity of the 24-inch is considerably less than that of the 36, as shown by the height of piezometer column at air valve 53, but whether this is due to changed conditions or to original lack of proportion, is unknown.

Moreover, if it is true that the bends are in any large degree responsible for the excessive friction in the 36-inch pipe, it follows, that where there are either no bends or only a few, the friction should be much less. Now what is the fact? From the gatehouse at Hemlock Lake to air valve 91, the alignment is not only nearly straight, but for a large portion of the distance the pipe is laid on a true grade. Just before reaching air valve 91, however, there are three bends of 14 degrees each. The hydraulic grade from the gatehouse to air valve 91 is 0.44, or 0.01 less than the mean grade for the entire distance to air valve 53. Again, from air valve 75 to air valve 74 the grade is 0.56, while in the intervening space there is only one bend of 10 degrees.

Table No. 5 gives the equivalent diameters of pipes which will allow the water now flowing to pass with only the loss of head per unit of length that has been found to exist by experiment with such pipes.

Taking the fundamental formula—

$$v = C\sqrt{RS} \quad \text{.........................(3)}$$

in which the mean value of C for these computations $= 117$ and substituting in it the equivalents of R and S, which are $R = \frac{d}{4}$ and $S = \frac{h''}{l}$, we have

$$v = C\sqrt{\frac{d}{4} \times \frac{h''}{l}} \quad \text{.....................(4)}$$

where d = diameter of conduit in feet,

h'' = head used in overcoming resistance in a distance l in feet as already found, namely,

for 36-inch pipe $h'' = 0.2$ in 1 000 feet, for 24-inch pipe $h'' = 1.60$ in 1 000 feet, and $l = 1\,000$ feet.

The general equation for velocity is:

$$v = \frac{Q}{F} \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Combining equations (4) and (5) there results:

$$Q = FC\sqrt{\frac{h'' d}{4l}} \dots\dots\dots\dots\dots\dots\dots\dots (6)$$

whence we determine $d = \dfrac{4lQ^2}{F^2 C^2 h''} \dots\dots\dots\dots\dots\dots\dots\dots (7)$

$$\text{and } d\,F^2 = \frac{4lQ^2}{C^2 h''} \dots\dots\dots\dots\dots\dots\dots\dots (8)$$

In this form the problem resolves itself into computing with known values of Q, l, C and h'', the value of dF^2, and then finding by inspection and trial such value of d as will, with its corresponding value of F, satisfy the equation. In this way the values of d, as given in the last column of Table No. 5, have been found.

TABLE NO. 5—SHOWING THE EQUIVALENT SIZE OF THEORETICALLY PERFECT PIPE FOR THE APPROXIMATE ACTUAL DELIVERY OF THE SEVERAL SECTIONS OF THE HEMLOCK LAKE CONDUIT OF THE ROCHESTER WATER-WORKS IN 1890.

Section of Conduit.	Equivalent Size of Pipe for Actual Delivery in inches.	Section of Conduit.	Equivalent Size of Pipe for Actual Delivery in inches.	Section of Conduit.	Equivalent Size of Pipe for Actual Delivery in inches.
Well House to A. V. 91	31	A. V. 68 to A. V. 67	29	A. V. 49 to A. V. 48	22
A. V. 91 to A. V. 38	33	" 67 " 66	33	" 48 " 47	23
" 88 " 87	29	" 66 " 64	32	" 47 " 46	21
" 87 " 79	31	" 64 " 63	31	" 46 " 45	24
" 79 " 78	32	" 63 " 62	31	" 45 " 44	22
" 78 " 77	32	" 62 " 61	32	" 44 " 42	23
" 77 " 76	31	" 61 " 60	27	" 42 " 41	22
" 76 " 75	31	" 60 " 59	29	" 41 " 40	24
" 75 " 74	30	" 59 " 58	31	" 40 " 39	24
" 74 " 73	35	" 58 " 57	31	" 39 " 38	21
" 73 " 72	32	" 57 " 56	31	" 38 " 37	24
" 72 " 71	32	" 56 " 55	29	" 37 " 36	24
" 71 " 70	32	" 55 " 54	33	" 36 " 35	24
" 70 " 69	31	" 54 " 53	32	" 35 " 34	21
" 69 " 68	30	" 53 " 52	20	" 34 " 33	19
		" 52 " 51	22	" 33 " 32	21
		" 51 " 50	23	" 32 " 31	20
		" 50 " 49	22	" 31 " 30	21
				" 30 " 29	20
				" 29 " 28	21
				" 28 " 27	21
				" 27 " 26	20
				" 26 " 25	22
				" 25 " 24	21
				" 24 " 23	23

The foregoing tabulation may serve to saliently illustrate the decreased capacity due to increase of hydraulic gradient.

Mr. Kuichling gives fresh water sponge as one of the principal causes of the present decreased delivery of the conduit. I do not agree with this. In February, 1888, in a paper on the Micro-organisms in Hemlock water, which I read before the Rochester Academy of Science, I called attention to the fact that at that time the spicules of fresh water sponge were present in every filtering. In the following months of May and June, Mt. Hope Reservoir was drawn off for repairs and an examination there revealed some considerable amount of sponge growing attached to the masonry in the outlet well. This was removed and the walls scraped clean. The bottom and sides of the reservoir and end of the inlet pipe were also examined at the same time without giving any further indication of the presence of sponge. In July and August of that year, Rush Reservoir was also entirely empty, and on examination no sponge was found. A similar examination was made about the same time, by raking the sides of the masonry of the well at Hemlock Lake. Scrapings from the screens at Hemlock Lake and the reservoirs were also examined microscopically several times during the summer and fall of 1888 and the following winter. In no case was any further indication other than occasional sponge spicules found, and inasmuch as the amount of sponge discovered in the outlet well at Mt. Hope reservoir in the spring of 1888 was probably enough to account for the spicules seen the previous winter, it was concluded that the cleaning of the masonry at Mt. Hope had removed their chief source. Since 1889 a number of microscopical examinations have been made, especially during last winter, without discovering more than an occasional sponge spicule. I therefore venture the opinion that fresh water sponge is not the chief cause of the trouble.

Is it not possible that what Mr. Kuichling really saw in the Rush Reservoir stop gate on September 19th, 1890, was not fresh water sponge, but fresh water polyzoa? The statoblasts of a number of species of polyzoa have been plentiful in the Hemlock water in the winter season for a number of years and it has always been something of a mystery as to just where they came from. Much searching at Hemlock Lake has thus far utterly failed to reveal them.

The substance stated to have been growing in the cast iron pipes, I have been unable to find, and the difficulty in the Hemlock Lake conduit is as shown entirely in the wrought iron pipes. We can hardly accept the sponge theory, therefore, unless it be proven that the sponge, or whatever other organism it may be, has a power of selection and prefers the wrought iron pipe to the cast iron.

It was found during the fall of 1890 that when an accurate pressure gauge at Mount Hope Reservoir registered 18 pounds and Rush Reservoir had a depth of from 14 to 16 feet, the flow from Rush to Mount Hope was just about equal to the inflow from Rush to Hemlock Lake; that is

to say, with 14 to 16 feet of water at Rush and the pressure gauge at Mount Hope showing 18 pounds, the delivery from Rush to Mount Hope was about 6 700 000 gallons daily, Mount Hope being also at from 14 to 15 feet. We have then the 24-inch cast iron line between Rush and Mount Hope Reservoirs delivering 6 700 000 gallons daily, the same as due to an elevation of 35 feet above water surface at Mount Hope. This is shown in Fig. 2, where the data applying are compiled. The pressure gauge in use at that time was set about 6.5 feet below the mean water surface at Mount Hope, and 18 pounds indicated pressure gives a total of 41.5 feet or 35 feet above Mount Hope water surface. The length of 24-inch cast iron main from the outlet at Rush to the point of inflow at Mount Hope is 46 840 linear feet, which gives, with a total loss of head of 82.4 feet for the delivery of 6 700 000 gallons, a hydraulic gradient per 1 000 feet equal to 1.76.

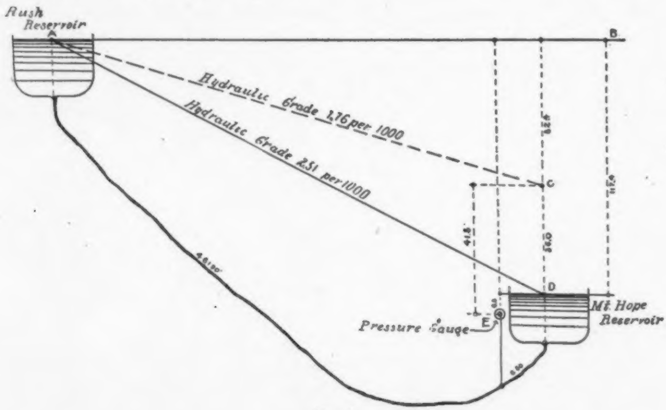


FIG. 2.

Substantially the same rate of grade also existed during the summer of 1891, as may be seen by the following table. It is fair to say, however, that a new self-recording gauge has also been set up at Mount Hope, and I believe it is about half a foot higher than the old gauge, or say 6 feet below normal water surface. Inasmuch as I have not got the detail of its location, I am obliged to base the argument on the known location of the old gauge.

Table No. 6 shows that with 17 pounds pressure at Mount Hope, Rush Reservoir slowly fell; while, with 20 pounds pressure, Rush slowly rose, and the movement is such, even after making the necessary allowances for evaporation, etc., as to indicate that the point of equilibrium is somewhat nearer 20 pounds than 17. Taking 18 as a safe figure, we obtain the rate of 1.76, as already indicated.

TABLE No. 6.—GIVING DAILY DEPTHS OF WATER AT MOUNT HOPE AND RUSH RESERVOIRS, AND THE CORRESPONDING INDICATIONS OF THE PRESSURE GAUGE AT MOUNT HOPE, FROM AUGUST 1ST TO SEPTEMBER 8TH, 1891.

Date.	Mount Hope, 7 A.M.	Pressure Gauge. Pounds.	Rush. 7 A.M.	Date.	Mount Hope. 7 A.M.	Pressure gauge. Pounds.	Rush. 7 A.M.
August 1..	13.33	20	14.74	21..	14.50	17	14.48
(Sunday) 2..	13.75	20	14.72	22..	14.33	17	14.46
3..	14.50	20	14.69	(Sunday) 23..	14.50	17	14.45
4..	13.08	......	15.26*	24..	15.23	17	14.41
5..	13.29	16	15.19	25..	15.12	20	14.42
6..	13.58	16	15.14	26..	15.00	20	14.44
7..	13.71	16	15.08	27..	14.83	20	14.48
8..	13.79	16	15.05	28..	14.58	20	14.52
(Sunday) 9..	13.92	16	15.00	29..	14.54	20	14.52
10..	14.58	16	14.97	(Sunday) 30..	14.58	20	14.55
11..	14.37	16	14.91	31..	15.25	20	14.52
12..	14.16	17	14.84	Sept. 1..	15.16	20	14.53
13..	14.21	17	14.79	2..	15.25	20	14.54
14..	12.92	......	15.22*	3..	15.08	22	14.60
15..	13.50	17	14.93	4..	14.92	22	14.71
(Sunday) 16..	13.92	17	14.80	5..	14.75	22	14.77
17..	14.62	17	14.75	6..	14.00	22	14.88
18..	14.54	17	14.68	7..	15.00	22	14.95
19..	14.50	17	14.60	8..	15.08	22	15.00
20..	14.50	17	14.55				

* Mount Hope gates shut part of the day.

This gradient of 1.76 per 1 000 feet in the 24-inch cast iron pipe between Rush and Mount Hope being nearly the same as that found in the same kind and size of pipe between Hemlock Lake and Rush, emphasizes the view that the difficulty between Hemlock Lake and Rush is chiefly in the wrought iron pipe rather than in the cast iron.

The use of mercury gauges has been suggested, and I admit that with abundant leisure, observations could be taken more accurately with them, than with ordinary metallic spring gauges. The use of the mercury gauge, however, is not altogether a simple matter, as scrupulous attention to a number of corrections becomes absolutely imperative in order to obtain results which are of any value at all; while with metallic gauges an observer who properly understands the limitations of his tool can quickly reach results which, although not accurate to the third and fourth decimal place, are still sufficiently accurate for most practical purposes.

In further discussing the subject matter of the papers, I give from official records Tables Nos. 7 and 8:

Table No. 7 is derived by use of the record of the pressure gauge at Mount Hope Reservoir from Table No. 8, which was computed by Mr. Nichols. The location of the pressure gauge and its relations to the reservoirs are shown in Fig. 3.

TABLE No. 7.—SHOWING THE AVERAGE DAILY USE OF WATER IN THE CITY OF ROCHESTER, FROM APRIL 1ST, 1876, TO APRIL 1ST, 1889.

TIME—April 1st to April 1st.	Total Use of Water for Each Year, in Gallons.	Average Use per Day, in Gallons.
1876–'77	813 202 600	2 227 953
1877–'78	1 052 530 300	2 883 650
1878–'79	1 159 687 250	3 177 225
1879–'80	1 409 186 850	3 860 785
1880–'81	1 584 513 942	4 341 134
1881–'82	1 546 898 500	4 238 078
1882–'83	1 653 056 800	4 531 662
1883–'84	1 763 054 100	4 819 809
1884–'85	1 950 392 200	5 343 540
1885–'86	1 881 019 200	5 153 426
1886–'87	2 107 399 000	5 773 695
1887–'88	2 207 928 800	6 032 565
1888–'89	2 299 663 300	6 300 447

TABLE No. 8.—SHOWING THE APPROXIMATE AMOUNT OF WATER PASSING INTO MOUNT HOPE RESERVOIR FROM RUSH AS INDICATED BY THE PRESSURE GAUGE AT MOUNT HOPE.

Indicated Pressure in Pounds.	Gallons per day as per Table in An. Rept. for 1876.	Gallons per day as per Table used at Mount Hope Reservoir.	Indicated Pressure in Pounds.	Gallons per day as per Table in An. Rept. for 1876.	Gallons per day as per Table used at Mount Hope Reservoir.
53	0	0	26	5 278 421	5 246 800
52	1 015 840	1 009 750	25	5 375 290	5 343 000
51	1 436 601	1 428 000	24	5 470 550	5 437 000
50	1 759 478	1 749 000	23	5 563 944	5 530 000
49	2 031 679	2 019 500	22	5 655 917	5 622 000
48	2 271 470	2 257 900	21	5 746 421	5 712 000
47	2 488 277	2 473 400	20	5 835 528	5 800 600
46	2 687 645	2 671 500	19	5 923 816	5 887 800
45	2 873 218	2 856 000	18	6 009 754	5 973 800
44	3 047 519	3 029 000	17	*	6 058 500
43	3 212 252	3 193 100	16	*	6 142 100
42	3 369 139	3 349 000	15	*	6 224 500
41	3 518 957	3 497 900	14	*	6 298 600
40	3 662 640	3 640 700	13	*	6 386 200
39	3 800 894	3 778 100	12	*	*
38	3 937 032	3 910 700	11	*	*
37	4 063 359	4 039 000	10	*	*
36	4 180 384	4 163 300	9	*	*
35	4 309 819	4 283 000	8	*	6 773 600
34	4 439 914	4 401 000	7	*	*
33	4 542 941	4 515 700	6	*	*
32	4 655 131	4 627 300	5	*	*
31	4 764 672	4 736 000	4	*	*
30	4 821 837	4 842 600	3	*	7 174 000
29	4 976 496	4 946 700			
28	5 079 197	5 048 800			
27	5 179 766	5 148 700			

* Not given in the record.

Table No. 8 was probably either computed with the formula $V = 100 \sqrt{RS}$, or by a slight modification thereof. As it has been shown that at the present time the 24-inch cast iron conduit between Rush and Mount Hope reservoirs delivers 6 700 000 gallons a day into Mount Hope, with a mean hydraulic gradient of 1.76 per 1 000 feet, it follows that at full performance this section of the conduit delivers considerably more. A discharge of 6 700 000 gallons a day gives for a 24-inch pipe $Qs_1 = 10.367$ cubic feet, and $Vs_1 = 3.300$ linear feet.

Taking a gradient of 1.76 per 1 000, we obtain for a delivery of 6 700 000 gallons from the formula $V = C \sqrt{RS}$ a value of $C_1 = 111$, and for full performance we have $S_1 = 0.00251$. With these values of S and V we get $V_1 = 111.0 \sqrt{0.5 \times 0.00251} = 3.94$, and for the daily discharge 7 999 500 gallons. In other words, if 6 700 000 gallons pass per day, when the Mount Hope pressure gauge shows 18 pounds, the full capacity between Rush and Mount Hope is practically 8 000 000 gallons per day.

In the same way, taking the daily discharge for 18 pounds pressure at 7 000 000 gallons as per Mr. Kuichling, and we obtain a value of $C_2 = 116$, with a daily discharge at full performance of 8 380 000 gallons.

Again, a daily delivery at full performance of 9 292 800 gallons gives a value for $C_3 = 130.2$.

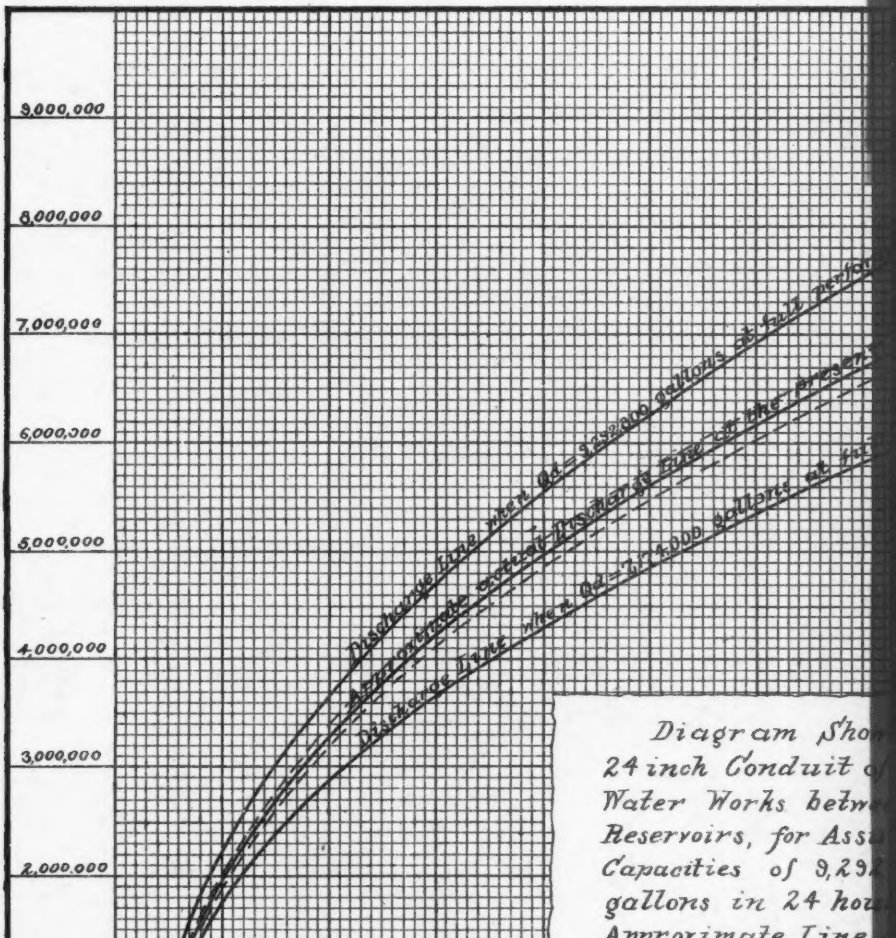
It is clear from the foregoing discussion that the statistics of daily use of water as derived from a tabulation computed on the assumption of full performance of this conduit of 7 174 000 gallons daily are considerably in error.

If we compare the values of v and Q_d for the several values 111.... 116....130.2, for various readings of the pressure gauge, we have the following tabulation:

TABLE No. 9.

Pressure gauge. Pounds.	Effective Head. Feet.	$v = c \sqrt{RS}$.				
		$c_1 = 111.0$		$c_2 = 116.0$		$c_3 = 130.2$
		(v)	Qd_1 in gal.	(v)	Qd_2 in gal.	Qd_3 in gal.
53	....	....	....	....	....	....
40	32.0	2 057	4 177 400	2 149	4 361 100	4 707 000
30	53.1	2 700	5 481 900	2 821	5 727 500	6 276 000
20	78.2	3 215	6 512 500	3 361	6 823 900	7 524 000
10	101.3	3 695	7 502 000	3 828	7 772 100	8 589 000
3	....	....	....	....	....	9 266 000

As intimated in my paper "On the Hydraulics," etc., I believe my measurements of flow into Rush Reservoir are 2 or 3 per cent. in error, and on reviewing all the circumstances I conclude they may be about



9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
Discharge in gallons per day.
A
50
45
40
35
30
25
Line of Pressures.
Discharge Line when Qd = 9,292,000 gallons at full perfor
Approximate actual Discharge Line at the present
Discharge Line when Qd =
gallons at fu
Diagram Show
24 inch Conduit o
Water Works betw
Reservoirs, for Assu
Capacities of 9,292
gallons in 24 hou
Approximate Line
at the present ti

Discharge Line when Qd =
Approximate critical Discharge
Discharge Line when Qd =
Line of Pressure
45
40
35

PLATE XV.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XXVI. Nº 521.
RAFTER. MEASURES FOR
RESTRICTING WASTE OF WATER.

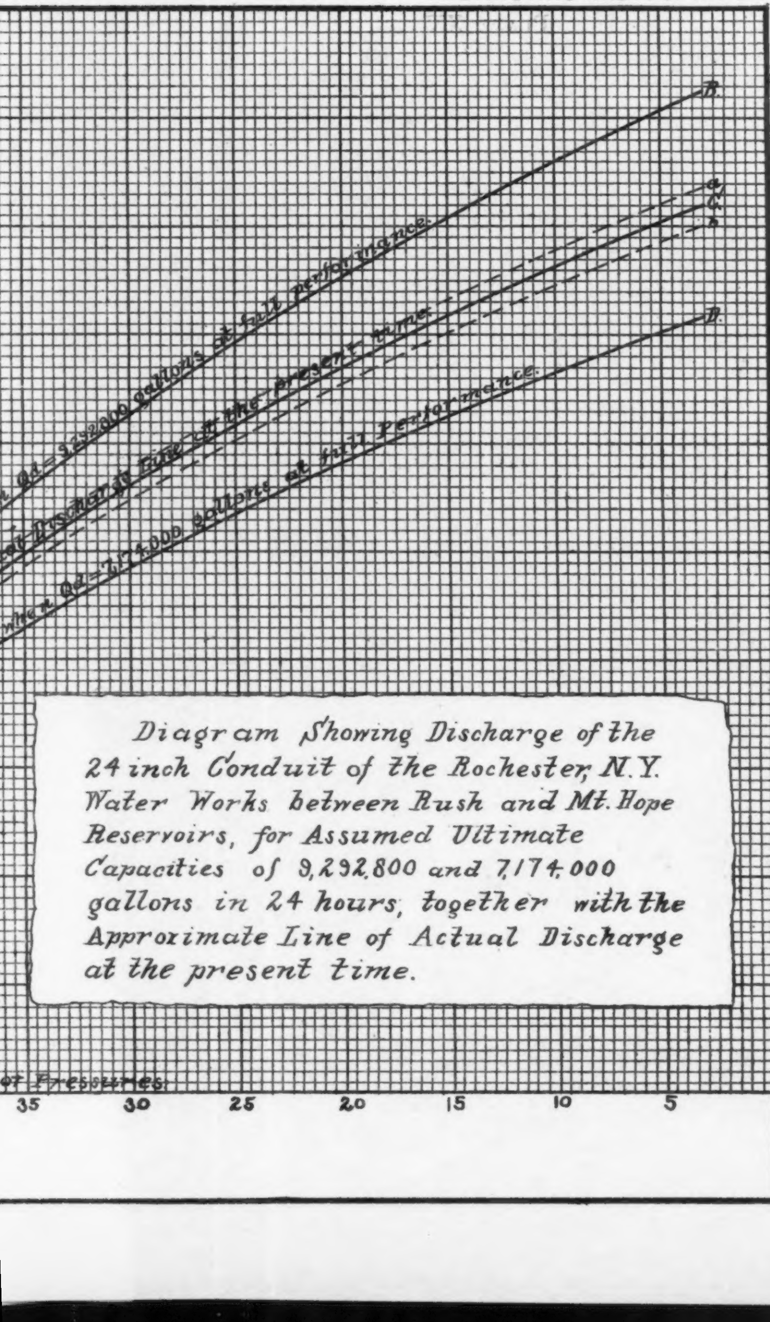


Diagram Showing Discharge of the 24 inch Conduit of the Rochester, N.Y. Water Works between Rush and Mt. Hope Reservoirs, for Assumed Ultimate Capacities of 9,292,800 and 7,174,000 gallons in 24 hours, together with the Approximate Line of Actual Discharge at the present time.

that amount too small. Mr. Kuichling's, I am equally satisfied, are somewhat too large, and the truth, therefore, lies between the two.

By way of briefly illustrating the matter graphically we may refer to Plate XV, where the discharge curves for the several different suppositions are shown, the curves *Aa* indicating the discharge for full performance of 7 000 000 gallons daily, as per Mr. Kuichling, while *Ab* is for 6 700 000 gallons per day. The mid-line, *Ac*, which probably represents the real discharge within a small limit of possible error, indicates for full performance a daily delivery of 8 200 000 gallons.

It is further clear that the discharge curves of Plate XV, furnish a convenient method of determining the true value of the quantities tabulated in Table No. 7. By its use we obtain the column "Total average daily use in gallons," in Table No. 10. It will be noted that the daily use for the municipal year, 1888 to 1889, is given as 7 250 000 gallons. The excess quantity is due to (1) draft on the storage, and (2) to increased delivery with low water at Rush Reservoir.

TABLE No. 10.

Hemlock Lake Water.				Average daily use of Holley water per head of population, in gallons.	Total average daily use per head of population from both systems, in gallons.
Municipal year. April 1 to April 1.	Total average daily use, in gallons.	Population.	Average daily use per head of the population, in gallons.		
1876 to 1877	2 500 000	83 600*	30.5	.....	.....
1877 to 1878	3 280 000	85 150	38.9	.....	.....
1878 to 1879	3 675 000	86 700	42.4	.....	.....
1879 to 1880	4 510 000	88 430	51.0	.....	.....
1880 to 1881	5 040 000	90 930	55.4	.....	.....
1881 to 1882	4 925 000	93 100	53.0	.....	.....
1882 to 1883	5 260 000	95 650	55.0	12.6	67.6
1883 to 1884	5 590 000	99 850	56.0	12.8	68.6
1884 to 1885	6 160 000	104 200	59.1	12.4	71.5
1885 to 1886	5 990 000	108 500	55.2	11.2	66.4
1886 to 1887	6 660 000	113 900	58.5	11.9	70.4
1887 to 1888	6 930 000	119 700	57.9	12.2	70.1
1888 to 1889	7 250 000	126 500	57.3	12.5	69.8

*Official population in 1875, 81 722; in 1880, 89 366; in 1890, 133 896. No additions to territory.

During the year from April 1st, 1888, to April 1st, 1889, the storage at Rush was exhausted, and for three months, from about the middle of July to about the middle of October, Rush Reservoir was either entirely or nearly empty. During this period the discharge from Hemlock Lake to Rush Reservoir was that due to a head of, say, $143.8 + 16.0 = 159.8$ feet. This head may be considered as giving, under the known conditions, a discharge of about 7 000 000 gallons per day.

At no time that year, after July, was there more than 8 feet of water at Rush, and for several months the quantity was less than this.

The following table is of interest in the general discussion of the subject in hand:

TABLE No. 11.—SHOWING THE APPROXIMATE USE OF WATER BY HOURS ON THREE DIFFERENT DAYS IN 1890. AS DETERMINED BY OUTFLOW FROM MOUNT HOPE RESERVOIR.

Hour.	Saturday, July 5th, 1890 (12-hour measurement).		Sunday, August 10th, 1890, to 7 A.M. of Monday, August 11th (24-hour measurement).		Monday, August 25th, 1890, to 7 A.M. of Tuesday, August 26th (24-hour measurement).	
	Hourly outflow in gallons.	Outflow in six hours in gallons.	Hourly outflow in gallons.	Outflow in six hours in gallons.	Hourly outflow in gallons.	Outflow in six hours in gallons.
7 A.M. to 8 A.M.	330 563	....	217 907	....	392 041	
8 " 9 "	374 220	....	260 911	....	355 035	
9 " 10 "	394 238	....	277 490	....	389 125	
10 " 11 "	366 163	....	285 393	....	387 659	
11 " 12 M..	392 583	....	250 098	....	333 590	
12 M. " 1 P.M.	330 497	2 188 264	258 079	1 549 878	332 493	2 189 943
1 P.M. " 2 "	373 238	....	248 800	....	348 811	
2 " 3 "	363 562	....	239 670	....	330 245	
3 " 4 "	345 789	....	204 907	....	277 078	
4 " 5 "	343 877	....	161 936	....	345 676	
5 " 6 "	341 381	....	212 638	....	292 693	
6 " 7 "	326 262	2 096 109	204 707	1 272 658	291 818	1 886 321
7 " 8 "	....	....	169 426	....	205 479	
8 " 9 "	....	....	186 026	....	143 816	
9 " 10 "	....	....	151 926	....	170 626	
10 " 11 "	....	....	118 004	....	170 326	
11 " 12 "	....	....	151 505	....	102 063	
12 P.M. " 1 A.M.	....	....	111 676	888 563	135 925	928 235
1 A.M. " 2 "	....	....	67 222	....	135 685	
2 " 3 "	....	....	134 146	....	101 643	
3 " 4 "	....	....	150 757	....	118 485	
4 " 5 "	....	....	100 326	....	135 204	
5 " 6 "	....	....	217 105	....	185 607	
6 " 7 "	....	....	266 463	936 019	286 080	962 704
Totals....	4 284 373	4 284 373	4 647 118	4 647 118	5 967 203	5 967 203

From Table No. 11 we derive—

TABLE No. 12.

TIME.	July 5th (Saturday). Gallons.	August 10th and 11th (Sunday and Sunday Night). Gallons.	August 25th and 26th (Monday and Monday Night). Gallons.
7 A. M. to 7 P. M.........	4 284 373	2 822 536	4 076 264
7 P. M. to 7 A. M.........	....	1 824 582	1 890 939
Totals............	....	4 647 118	5 967 203

It appears from the foregoing that the purely domestic use of water, including leakage in services and the distribution system, as indicated

by the Sunday measurement, was, while the restrictive measures were sharply in force last year, say, 4 650 000 gallons a day, amounting for a population of 134 000 to 34.7 gallons per head per day. The difference between the Sunday and Monday measurement further indicates that the use of water for manufacturing purposes was, with some allowannce for increased domestic use on Monday, perhaps 1 200 000 gallons per day. Mr. Tubbs, however, claims that the adoption and continuance of the restrictive measures has led to a reduction in the use for manufacturing purposes of at least 1 500 000 gallons per day.

When the Rochester Water-Works were first constructed a number of large consumers were supplied at a rate of 3½ cents per 1 000 gallons, or at a price, when the fixed charges are taken into account, of about one-third the actual cost per 1 000 gallons to the city. For conservative figures we will say that the amount of water sold in the last ten years is 1 000 000 gallons a day over what it would have been if the price in the beginning had been made cost plus a small profit. 1 000 000 gallons per day, at 3½ cents per 1 000 gallons, amounts to $12 775 per year. At 11 cents per 1 000 gallons, which is a trifle more than the actual cost, the yearly sum for 1 000 000 gallons a day becomes $40 150. The difference of the two is ($40 150 — $12 775) = $27 375; we therefore reach the result that in ten years the City of Rochester subsidized a few large consumers to the amount of $273 750. A couple of years ago the Executive Board placed the price at 11 cents per 1 000 gallons for quantities over 5 000 gallons per day, and a few establishments accordingly sought their own sources of supply as a measure of economy.

In regard to loss of revenue the following are the official figures: The total receipts of the Rochester Water Works during the year 1889 were $169 879.72; during 1890 they were $211 743.94; while in 1891 they were $251 576.21.

Mr. Thomson in his discussion states he is willing to go on the record as in favor of limiting the supply by pinching the valves carefully down "at some lower portion of the hydraulic gradient beyond the principal distributing area"; and this he says would be preferable to partially closing the gates at Mount Hope Reservoir. If he will read carefully what I have written on this point in the second paper, and further examine the map (Plate XIV), he will see that the thing which he states as preferable is precisely the thing done, and I am greatly obliged to him for thus strongly emphasizing the utility of the design. His view, that the necessary restrictions could have been obtained at all, in 1890, by so closing the supply gates at Mount Hope as to allow the feeding mains leading therefrom to run just full, is probably due to a lack of full information as to the detail. The center of the supply gates is 18.5 feet below the normal water surface of 15 feet above reservoir bottom; 8 pounds is therefore the maximum possible reduction at this point. It would, however, be desirable to leave a little

pressure on the city side of the supply gates, in order to provide for the contingency of a sudden increase of draft. Making such an allowance and taking say 5 pounds as about the practicable limit of reduction of pressure, by closing the supply gates at Mt. Hope Reservoir, this could only be attained by keeping the depth of water in the reservoir at fully 15 feet. As stated in the paper, the general lowering of pressure actually attained was from 10 to 20 pounds.

As to the originality of the method of reduction actually applied, the claim is that the combination of the fire alarm gong, telephone and pressure gauge was a new and useful application of modern appliances to the specific problem in hand.

The actual results obtained in increasing the storage are shown by

TABLE No. 13.

Date.	Mt. Hope. Depth in Res., in feet.	Mt. Hope. Corresponding Quantity of Water as Derived from Mr. Nichols' Table, in Gallons.	Rush. Depth in Res., in feet.	Rush. Corresponding Quantity of Water as Derived from Mr. Nichols' Table, in Gallons.	Total Net Gain at both Reservoirs = (3) + (5), in Gallons.	Total Net Gain + the Evaporation, divided by 60, the number of days, $\frac{49\ 668\ 600}{60}$ in Gallons.
Sept. 15 at 7 A. M.	15.50	23 383 000	16.35	62 741 700		
July 17 at 7 A. M.	10.82	15 372 800	6.95	24 733 300		
Gain............	4.68	8 010 200	9.39	38 008 400	46 018 600	
	Evaporation at 0.2 inches per day over the mean area, =				3 650 000	
	Total net gain + the evaporation, =				49 668 600	827 810

A few words as to the probable causes of a smaller delivery in this conduit than theory indicates.

(1) It appears that the spigot end of the 36-inch pipe was made by a small fillet of half round iron. This has been found in practice altogether too light, the effect of sharply setting up the lead (as I have myself seen) being to kink the spigot end, with the result that the oakum and lead project into the interior of the pipe. The whole number of joints on the 36-inch pipe is about 1 000, and during the thirteen years ending December 31st, 1890, a total of 557 leaks have been repaired.

(2) If posts have been inserted to resist earth pressure on the wrought pipe, their presence, in connection with the high grades on the same sections, is strong evidence of a number of deformations where the pipes

are covered deeply with earth, and such deformations would tend to cause increased resistances.

(3) When the deficiency in delivery was first definitely determined, in 1890, Mr. Tubbs was strongly of the opinion that the chief cause was floating obstructions, and extended inquiry among men employed upon the original construction indicated that probably some pieces of plank and timber had been left inside the pipe. If this view of the matter be entertained it may explain the irregular action at air valves 55, 56 and 57. It would also be a full explanation of the discordant piezometer observations at those valves. The piezometer measurements seem to indicate that floating obstructions are not the chief cause, though they may contribute to the difficulty.

(4) The relation of the hydraulic gradients in the two sections of wrought iron pipe indicates that as a whole the same cause has been operative in both pipes. From the theory of flow in conduits we derive that under normal conditions, with the same discharge, the rate of hydraulic gradient in a 24-inch pipe should be about 7.7 times what it is in a 36-inch pipe. An application of this principle has been made in the discussion of Mr. Gould, and it is unnecessary to elaborate in reference thereto in this place. The rate of about 3.50 as the approximate probable value for the 24-inch wrought pipe, divided by 0.45, the mean value for the 36-inch pipe, gives a ratio of 7.8, which by itself is, as Mr. Gould has pointed out, the very strongest confirmation of the correctness of my deductions from the observations. The first part of Mr. Hering's discussion also embraces the same view from a slightly different standpoint. I infer, therefore, that the original roughness of the interiors of the built up pipes, together with a probable tuberculation of the same, exercises a very material influence in increasing the retardation, and is one of the chief causes.

On this head it may be noted that wrought iron is *per se* a material more liable, in the absence of a proper protective coating, to corrosive action than cast iron.

(5) There may be some adhering plant and animal life, though this explanation involves serious difficulties, as already pointed out. In any case, I venture the opinion that plant and animal growths are not the chief cause of the difficulty.

(6) There may be some undiscovered leakage, though Messrs. Tubbs, Kuichling and myself all agree, I believe, that at the present time the leakage is nearly *nil.* For the last year and a half both line foremen have carried a waterphone and an iron probe on their daily inspections, using them wherever any indication of a leak could be found, and it appears difficult to assume any large amount of undiscovered leakage. Again, the soil through which the line is laid is, with the exception of the first mile and a half from Hemlock Lake, mostly clay, some of it very heavy, and it may be considered settled that leaks, when

appearing at all, except on the mile and a half in question, which is quicksand and rock, show upon the surface. The piezometers show, however, that the first mile and a half has about the mean grade of the whole 36-inch section, thus effectually negativing the theory of excessive loss from leakage on this part.

The second part of Mr. Hering's discussion confirms this view. Thus he makes a slight allowance for departure from theoretical conditions, and falls 6 per cent. short of the original determination of 9 292 800 gallons. By repeating his computation with a value of n, appropriate to the known conditions of this conduit, he will obtain about 8 000 000 gallons as the original daily flow.

As the result of the discussion we may say:

(1) That the average rate of hydraulic gradient in the 36-inch pipe is in reality about 120 per cent. in excess of that for clean pipe, instead of 50 per cent., as stated in the first paper.

(2) That in the 24-inch wrought iron pipe the hydraulic gradient is from 120 to 135 per cent. in excess of the normal with the observed discharge.

(3) That in the cast iron mains of the Hemlock Lake conduit the hydraulic gradient is only from 10 per cent. to 34 per cent. in excess of the normal, with a mean value of the excess of about 22 per cent.

(4) From all the foregoing we may fairly conclude that the built up conduits, if used at all, must be constructed with the greatest care and with special attention to strict compliance with theoretical conditions.

(5) Experience in the Hemlock Lake conduit of the Rochester Water-Works indicates that as between cast iron and wrought iron, cast iron is on the whole the preferable material for water pipe lines, and that the legitimate sphere of use of built up pipes is only reached when, by reason either of large diameter or heavy pressure, or both, cast iron becomes inapplicable.

(6) Mr. Gould's point that it is unwise to put too much faith in hair splitting formulas is well taken, and we may go a step further and say that even a little allowance for future contingencies may be properly made.